Popular Astronomy.

Vol. III. No. 7. MARCH, 1896. Whole No. 27.

THE DISCOVERY OF AN UNSEEN BODY IN THE STELLAR SYSTEM, F 70 OPHIUCHI.

ERIC DOOLITTLE.

For Popular Astronomy.

The wide double star, F 70 Ophiuchi is in many respects the most interesting stellar system which has yet been investigated. Its great beauty could not fail to have attracted the attention of observers from the time of its first discovery by Herschel, but it is of more importance that its motion has ever since shown peculiar and unexplained anomalies.

F 70 Ophiuchi is an easily visible, equatorial star, ($\alpha = 18^h\ 02^m$ $\delta = 2°\ 33'$), which has hitherto been supposed to consist of two components, of the fourth and sixth magnitudes respectively. The apparent orbit is a narrow ellipse, as shown in the diagram, of such size that the two stars can almost always be readily separated by small telescopes. It is then seen as a beautiful object, the large star being an orange yellow and the smaller one a purplish red.

Ever since Struve began his measures in 1825, this system has justified Mädler's description as "*Ein wahres experimentum crucis tur den Berechner*" (a veritable crucial test for the computer). Many observations of it were recorded by Herschel and Struve before 1825, and since that year the list is practically continuous until the present time. Possessing thus more recorded observations than any other double star in the northern heavens, this system has also had more orbits computed for it than any other, but thus far the companion has declined to move in any of them.

The motion has been, indeed, so refractory that it excited notice from the first. Mädler discussing the measures from 1779 to 1841, even concluded that the law of gravity did not hold good in this system, and Jacob some years later suggested that the system might be disturbed by an unseen body. Sir John Herschel was, however, "by no means prepared to grant" that there existed "deviations from an elliptical motion too considerable to arise from mere errors of observation." The suggestion of Jacob seems indeed to have been regarded as of little importance, for neither he nor any of the later computers attempted to make

use of it. It was therefore practically lost sight of, although the supposition was incidentally referred to by Klinkerfues in 1858.

The last of all the orbits which have been computed for this star was published by Professor William Schur, the successor of Gauss at Göttingen. This was the result of a most elaborate and able investigation based on over four hundred observations, to which the orbit was adjusted by the method of Least Squares. Professor Schur had treated the subject in the most exhaustive manner. Some attempt was made to determine the nature of the errors of each observer: the observations were grouped, and the corrections for personal equation carefully applied, the result being an orbit which satisfied all of the observed *angles* with remarkable accuracy. It was naturally expected that this orbit would represent the observations for many years to come.

Professor Schur's investigation was published in July, 1893. During the summer of 1895, in the course of his recent revision of all of the available orbits of double stars, Dr. T. J. J. See, of the University of Chicago, began a careful examination of this orbit.

Dr. See's method of determining an orbit differs from Professor Schur's in this, that while Professor Schur makes use only of the position angles of the companion, Dr. See uses the distances as well. Thus, while Professor Schur obtained an orbit which satisfied the angles with great precision, Dr. See endeavored to obtain one which would satisfy the distances also. In this, after much labor during which the computation of the orbit was carried completely through no less than eight times, he was unsuccessful. It appeared impossible by any change of the elements to avoid long columns of residuals which maintained the same sign for many years together.

The orbit which was finally found to give the best results is the heavy ellipse shown in the figure.

The failure of Schur's ellipse to agree even approximately with measures made four months previously, had convinced Dr. See of the necessity of this investigation. After completing his own orbit, he drew that of Professor Schur upon the same diagram, when he was much surprised to see how remarkably it violated the observed distances. Thus, between the years 1825 and 1846 every mean observed position lies without Schur's orbit, while between 1848 and 1862 every one lies within it. In the paper on this subject in the *Astronomical Journal* of January 9th (No. 363), he says: "A glance at the figure will show the improbability of such classic observers as Struve, Bessel and Dawes making the

constant errors thus indicated. * * * How has it happened that from 1825 to 1845 the distances were steadily over-measured by the best observers, while during the next period the distances were constantly undermeasured? Professor Schur's corrections are evidently inadmissible."

Additional measures soon indicated that the companion was rapidly leaving Schur's orbit; the error in position angle announced in the *Astronomical Journal* of November 13th was nearly five degrees. This sudden deviation from an orbit which had been carefully adjusted to so many observations could only arise from some disturbing cause. After a close study of the diagram, together with the computations, Dr. See had therefore announced that the system contained a dark body, and that no satisfactory orbit could be obtained until its motion was taken into account.

We will consider how this dark body probably moves, and how it happens that Schur's orbit has accurately represented the observed angles for so long a time, only failing to do so during the last two years.

The dots on the diagram are the observed positions of the companion at the different dates, the motion about the central star being retrograde, (with the hands of a watch). The two orbits intersect at about the year 1818. Were there no disturbing body in the system, the companion, starting from this point, apparently would move along the dark ellipse always describing in its motion equal areas in equal times.

Instead of this, however, it gets much ahead of where it should be on the ellipse, moving too rapidly until about 1846, when it begins to fall behind until 1872, after which it again moves too rapidly until 1892. Between 1818 and 1846, therefore, the area annually swept over by the radius vector would be abnormally great, if the body moves in the dark ellipse, a difficulty which Schur overcomes by drawing his ellipse in between these dates, as shown in the figure.

In the same way it is found that between 1846 and 1872 the body moves too slowly if the law of equable areas is to be obeyed. Here, therefore, it was necessary for Professor Schur to run his orbit outside of the observations and thus increase the areas, which he could do since he took no account of the distances in his computation.

The presence of this irregular motion may also be rendered evident in a very different way. If we examine all of the orbits which have been computed, it will be seen that the period of rev-

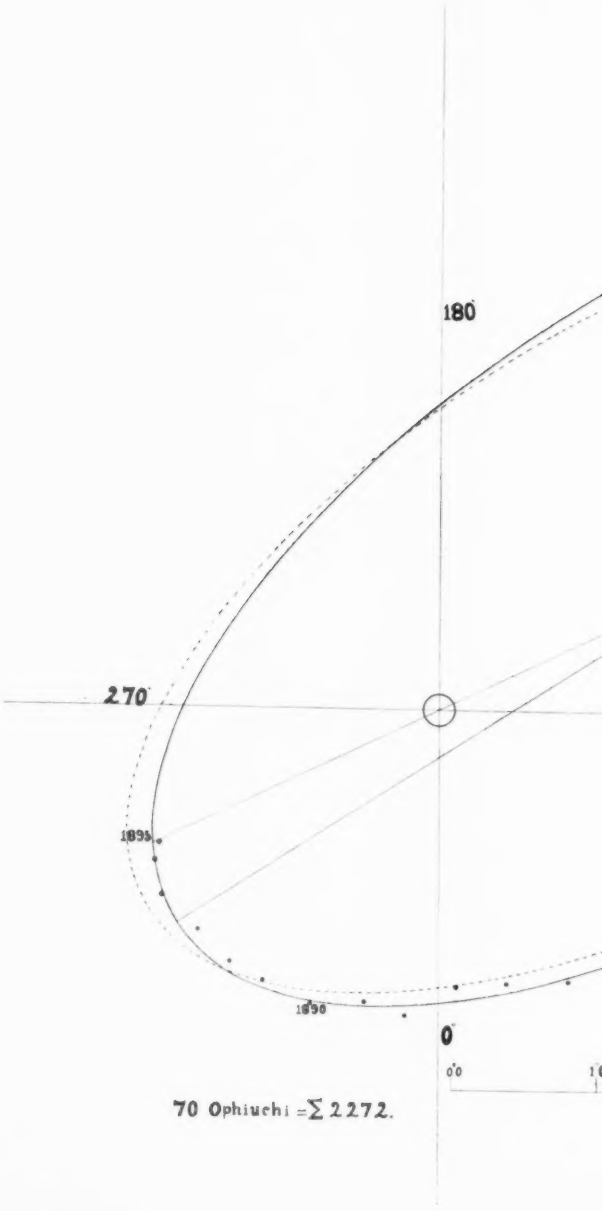
olution of each one which was determined before 1850 is (with but one exception) less than ninety years. Those, however, published between 1851 and 1878 are all greater than ninety-two years, since which time every published period is less than eighty-nine years. This shows that when observations began to include the abnormally slow motion between 1851 and 1878 the periods became too long: when observations in the too rapid portions of the orbit predominated the computed periods became shorter.

It will thus be seen why there was great difficulty in finding a simple orbit which should represent both angles and distances correctly, since if the body were supposed to move on the dark ellipse the observed angles would be constantly either too large or too small, while if Schur's orbit were adopted the distances would be violated.

Let us now imagine that there is a dark body near the bright companion, and that they revolve about the common centre of gravity in a retrograde direction. Suppose that in 1818 the two bodies lay in a tangent line to the orbit, the dark body being ahead; suppose also that the centre of gravity moves along Schur's ellipse, with the bright body at first on the outside. Then the motion of this visible star will evidently at first be accelerated and the distance from Schur's orbit continually increased. If we choose a period of thirty-six years for the dark body, then in 1836 the two companion stars will be in line with their first position, the bright star now being in front. In 1845, the two stars will again lie in a tangent to the ellipse, but immediately after this year the dark body will lie on the outside of Schur's orbit while the bright one will lie within it, and the motion of the latter will here be abnormally slow.

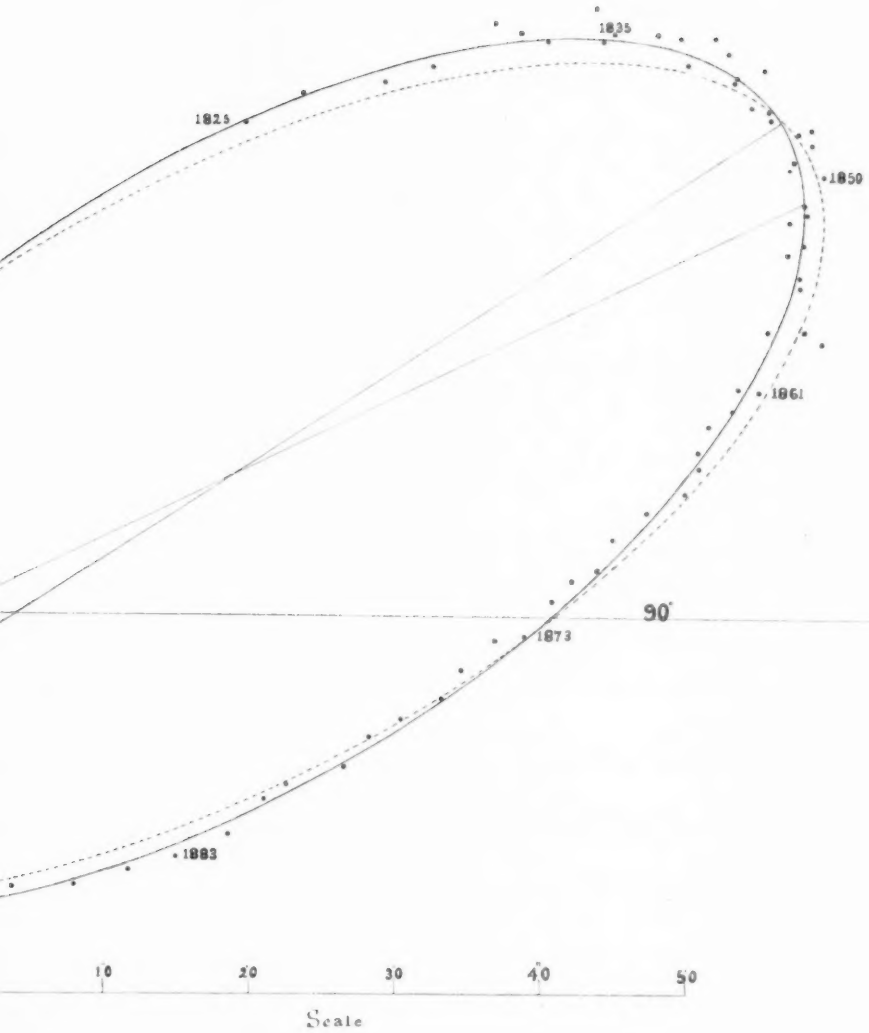
Though by drawing the dotted ellipse in and out, the angles might be well represented during two-thirds of a revolution, yet since the periods of the dark body and the companion are not commensurable, it would evidently have been impossible for a single ellipse to continue to represent them after the last intersection in 1892.

Upon assuming a small orbit for the bright companion, it was found that both in 1825 and in 1893 the position angle of the centre of gravity was the same as that which would be given at these times by Schur's orbit. The period of this orbit is also about the mean of all the periods thus far found. For these, and similar reasons, Dr. See has chosen this orbit as an approximate path of the center of gravity.



70 Ophiuchi = Σ 2272.

PLATE XII.



It would also have been possible to have explained all of the phenomena, by assuming, as Jacob suggested, that the central star itself is double. Under this supposition the system would be less stable than under the one here described, for the long period of thirty-six years would require a considerable separation of the central stars. On account of the smaller mass of the companion, the assumption that it is double renders a very much smaller separation sufficient.

The problem of determining the elements of the small ellipse in which the bright companion revolves, is one of the greatest difficulty. Even should its focus adhere strictly to Schur's orbit, the influence of the central star would cause a revolution of its line of apsides and other perturbations of a very complex character. The hypothesis which has been found, by trial merely, to satisfy the observations best thus far, is that of a small ellipse of the same shape and inclination as the large one. Its semi-major axis is but three-tenths of a second in length, and it is inclined to that of the large ellipse in an angle of thirty degrees.

If we assume the parallax of two-tenths of a second for this system, employed by Schur, it will follow that the dimensions of the larger orbit are about midway between those of Neptune and Uranus, while the major-axis of the smaller one is about as great as that of Mars. The combined mass of the three bodies would be about one and six-tenths that of our Sun. Thus the system is a truly magnificent one.

With regard to the small ellipse, however, it must be observed that as the observations are very inexact for determining such small quantities the values here given can only be regarded as a rough guess at the truth.

Since the publication of Dr. See's paper, observations have been received from Maw, Schiaparelli, Bigourdan and Glasenapp, which show the same departure from Schur's orbit which the theory here outlined would require. The further investigation of this remarkable system will constitute a problem in Physical Astronomy in some respects not inferior to that arising from the action of Neptune upon Uranus.

CHICAGO UNIVERSITY, February 1, 1896.

THE SPECTROSCOPE IN THE STUDY OF VARIABLE STARS.

TAYLOR REED.

FOR POPULAR ASTRONOMY.

Variable stars have long afforded amateurs a field for persistent and valuable work. With the application of the spectro-

scope the whole subject of variable stars has increased immeasurably in philosophical importance; and it seems unfortunate that for many valued observers the beauty and force of the physical facts and deductions of this advancing and thought-stimulating subject remain unappreciated and unknown.

From the first it has been noticed that many of the variable stars are red; and that a very red star is almost surely variable. So much is this true that in Chandler's catalogue of variable stars (*Astronomical Journal*, No. 300) there is a special column giving the redness of all stars on a scale of 0 for pure white and 10 for the purest red known in the sky. A glance down this column will show in how large a fraction of the whole number of known variables the redness is considerable; this in spite of the fact that red stars in the sky are few. Further, in the case of stars of long period of variability a distinct relation has long been known between the color of the star and the length of the period; the longer the period the redder the star. As to type of variability the red stars are those of irregular fluctuations or of long period (o Ceti type); and the 'new' stars (like Nova Auriga), though sometimes not red, are closely related to the red variables. The stars of the Algol type are white in color and different utterly in appearance, in spectrum type, and in physical explanation.

These red variables give spectra commonly referred to as third type (following the usual notation where white stars like Sirius are said to yield first type, yellow stars like Capella second type, red stars like Betelgeuse third type). The characteristic of this class of spectra is the presence of strong unsymmetrical dark bands, where the other two classes have only lines. In most of the spectra of this third type the bands are bounded sharply at the violet side and shade gradually out toward the red; but in the spectra of a small division of the class, the bands are turned the other way, sharp at the side toward the red. In all these red stars the violet end of the spectrum is incomparably weak, so that to photograph the violet end of the spectrum is most difficult.

A spectrum of this class does not declare a star a variable; it only makes it worth watching. But another thing does, anywhere and always, proclaim that a star is certainly variable: the presence in its spectrum of bright lines of hydrogen and of helium instead of dark lines. So that now the discovery of variable stars is accomplished, not by a tedious watching of a multitude of stars, but by hunting in a general spectroscopic survey for

spectra containing bright lines; the question of variability is then examined, and the variability does not fail of confirmation.

The appearance of bright lines in the spectra of long period variables is at time of maximum, roughly; but is very capricious. During the considerable time of minimum the bright lines are absent; the lines of hydrogen are dark. The bright lines vary in intensity in different stars, and at different maxima of the same star, and are generally irregular in their behavior.

New stars have in common with long period variables the presence of bright lines. The general spectrum contains dark absorption bands; but the bands are wholly unlike the shaded bands of third type spectra. The bright lines too, are more numerous usually in the temporary stars, including some lines of the Sun's chromosphere; and, growing in prominence with the star's age, the chief nebula line. Sometimes the lines have been sharp as in Nova Coronæ of 1866. In Nova Aurigæ of 1892 the lines were very broad, with dark absorption lines equally broad beside them. Unlike the variables of long period, however, the bright lines of the Nova increase in prominence as the star fades out. And that astounding and inevitable transformation from such a spectrum to the spectrum of a planetary nebula has neither correlative in ordinary variable stars nor rational explanation as a physical fact.

What shall be said of the regular concurrence of redness and banded spectrum in variable stars? A question, evidently, for the laboratory, rather than for the Observatory proper. And much remains to be done in the laboratory before the answer can be conclusive. Enough has been found, however, to indicate that such banded spectra are the result of chemical compounds, and so of low temperature. In accepting this much, that the temperature of such stars is much lower than that of the stars of the first two types, all spectroscopists agree.

To account in full for the variability of stars of bright line spectra, periodic and irregular and temporary, there have been theories without end; theories of great diversity and of abundant mutual contradiction; some theories possibly with a little truth; scarcely a theory without most suggestive and stimulating considerations. The earliest of the many speculators held, that one side of the variable is dark as if much more nearly covered by sunspots than the opposite hemisphere, so that by a very slow axial rotation the bright portion of the surface is periodically presented to us; their opponents have successfully urged the irregularity in period of all such variables and the improbabil-

ity of such a slow rotation. Some argue that the maxima are times of very energetic outbursts of physical activity in these cooler suns, making the times of greatest brightness the times of sun-spot maxima (not of sun-spot minima) and of frequency of eruptive prominences; while their opponents urge that in our own Sun at least little more or no more hydrogen is seen at sun-spot maximum than at minimum, and that one year is very short for a circle of solar activity. Some maintain (these in high disfavor just now), that in these less heated suns a slag forms at the surface which at intervals roughly regular is broken to pieces, revealing the interior heated matter. Others assume that these variables and temporary stars are double, an extensive atmosphere being tidally disturbed at periastron, so that physical activity is provoked. Still others contend that these same stars are not continuous double bodies at all, but two swarms of meteorites, each swarm revolving about the common centre of gravity of the two, and that the light is produced by violent collisions of outlying members of the two swarms, these collisions most frequent and violent at time of periastron; in fact, in the case of temporary stars, occurring only at the periastron, of an almost parabolic orbit.

Different entirely from the ordinary temporary stars in all but the superficial fact of being temporary, was the new star of 1885 in the Nebula of Andromeda. Its spectrum did not differ at all from that of the surrounding nebula, and remained the same through all its variations of brightness.

These stars of the Algol type form by themselves a very distinct type of variables. The manner of their variation,—an occasional diminution of their light for a short time,—and the precise constancy of their period of variation led at once to the theory of a partial eclipse of a brighter by a darker body, the two physically connected. Of the recent magnificent demonstration of the truth of this theory by showing the motion of the bright body away from us a quarter of a period before eclipse, and its motion toward us a quarter of a period after eclipse, it is scarcely necessary to speak; in fact already some investigators wish to explain even the irregularities in the Algol variables by the presence of a third body in the system or by the eccentricity of the orbit.

The variable β Lyræ has been much studied and its future study will be a matter of great interest. Bright lines occur in the spectrum, and oddly enough dark lines are superposed upon them; so that dark and bright lines are seen close side by side; or the bright line may be double with a dark line between the two

parts. The bright and dark lines seem to shift back and forward across each other; in such manner that from principal minimum to secondary minimum the bright lines are at the side of the dark lines toward the red; and in the other half at the side toward the blue. The usual assumption is for the present, that the star is a binary with two components giving unlike spectra, one of the two giving the bright lines; or, since this leaves serious outstanding irregularities, that it is a more complicated system containing bodies giving at least two kinds of spectra.

Of these various spectroscopic phenomena the observation of some is well within the reach of many amateurs The observation of orbital motion in the Algol stars and the study of the more delicate of the phenomena of β Lyræ require of course much more elaborate equipment than the average amateur possesses. But an elementary study of the red stars which are variable requires, and has required even for splendid work, but a meagre outfit; in fact, even with a great telescope, the Observatory's most modest spectroscope will in some particulars give the best result. The advantage, indeed, of such study does not lie merely in the more complete and interesting observation by amateurs of variable stars; the transcendent gain would consist in general familiarity with, and education in, those great principles of physical philosophy which are there so plentifully, though a little wildly, applied.

A METHOD OF MEASURING THE DISTANCES, DIMENSIONS AND MASSES OF BINARY SYSTEMS BY THE USE OF THE SPECTROSCOPE.

F. R. MOULTON.

For Popular Astronomy.

The delicate instruments and refined methods of modern astronomy have furnished us with a very accurate knowledge of the dimensions of the solar system and the masses of its separate bodies. The important problems connected with this work have long engaged the persevering care of observers, while the calculations of perturbations and ephemerides have taxed the utmost skill of mathematicians and have presented difficulties which, indeed, have not yet been entirely overcome. The Sun, planets and their satellites have been found to form a system of the most gigantic proportions and wonderful variety, yet maintained by simple laws.

The minds of such philosophers as Kant and Laplace were not satisfied with the contemplation of the grandeur and marvels of the system as we now behold it, but entered the higher science of cosmogony, which explains the laws and manner of its development and enables us to predict its future. The nebular hypothesis was the result of this scientific philosophy. The later researches of Helmholtz, Lane, Thomson, Darwin and others teach us the story of our system from a time more remote than the history of man, or of animal life, or of geologic changes—from a time when the Sun and the planets were one vast nebula rotating with slow motion and governed by the law of gravity; they teach us, too, that in the ages to come the rotation periods of the planets will be slowly ground down by tidal friction, and that the satellites will be driven farther and farther away from their primaries for countless centuries and then brought back and into collision with the planets around which they revolve; they teach us finally that the Sun, continually wasting his heat in space and contracting will eventually become dark and cold and continue so forever unless he collides with some other large body.

But these problems are only a small part of those which appeal to the astronomer. There are myriads of stars whose origin, constitution, size, distance and mode of evolution must be understood before any sound cosmogony for the universe can be formed. Until a large number of them are investigated we cannot tell whether the structure of our system is an exception or not. The difficulties in the way of accomplishing this have seemed in general insurmountable, but in recent years astronomers have had reason to hope much from binary stars. In the case of single stars we cannot do more than to measure their parallaxes, and even that is a very difficult task and can only be accomplished with those which are nearest to us; but when we can get the distance of a binary star whose orbit is known we have at once also the absolute dimensions and mass of the system.

The operation of measuring the parallax of a star is one of the most delicate in the whole range of practical astronomy and heretofore has been done by one of two methods, the *absolute* and the *differential*. The first consists in determining, by direct measurement of position, the displacement which the star has in consequence of the Earth's revolution around the Sun. The results to be found are so small and the difficulties so great, because of the instability of the instruments and the changes of the

seasons, that the accidental and systematic errors often entirely mask the parallax. The second method consists in measuring, with the micrometer or heliometer, the change of position of the star whose parallax we desire to know with reference to others which are apparently near. If the comparison stars are much more remote so that their parallax is insensible compared to that of the principal star our result would be theoretically correct, but of this condition we are never sure. While this method avoids many of the difficulties which attend the other, the results obtained give us only an undetermined part of the parallax. The parallaxes of forty or fifty stars have been measured in this manner but in no case except that of α Centauri does the value deduced exceed 0″.5. Where the parallax is 0″.1 or less the probable error is so large that the results cannot be relied upon, and the most discordant values are obtained by different observers. For example, Peters obtained a parallax of 0″.226 for 1830 Groombridge while O. Struve four years later by the same method found it to be 0″.034 or only about one-seventh as large. We must remember that the amounts to be measured are very small, 0″.1 being the angle subtended by one-quarter of an inch at a distance of eight miles.

At present it appears highly improbable that either of these methods can ever give us much knowledge of the great number of suns in the immensity of space; but a new method, depending upon the use of the spectroscope in the case of binary systems whose orbits are known, has recently been developed in an article by Dr. See in *Astronomische Nachrichten*, No. 3314 and promises to be of the highest importance. As will presently be shown it furnishes the possibility of obtaining the parallaxes of systems much farther away than can ever be measured by any other method, and at the same time gives the combined masses of the components and their distance apart. For the mathematical development of the method the reader should consult *Astronomische Nachrichten*, No. 3314; the fundamental idea may be stated as follows:—Suppose that we have micrometrical measurements of a binary star extending over a large part or the whole of a revolution so that the elements of its orbit can be well determined. From the theory of elliptic motion we can then calculate its angular velocity at any time. Since we know all the elements we can tell what part of the actual motion is toward or from the Earth. Suppose that for a given time we find that half of the motion of the companion is towards the Earth. We now apply the spectroscope to determine the relative motion of the two

stars by the displacement of the lines of their spectra. Suppose that we find that the relative motion of the companion in the line of sight is ten miles per second, then its real velocity in the orbit is twenty miles per second. As we have said before we can determine how large an arc it will describe in a given time and that leaves us with the problem of obtaining the length of the radii vectores when we have given the length of the arc of a known part of the ellipse in absolute units and the angle subtended by it at the focus. This can be done by elliptic integrals; or more simply, we may take a very short interval of time and consider the motion uniform in which case we have the arc of a circle given in degrees and linear measure, to determine the radius. This will be the radius vector of a known part of the ellipse in absolute units, as miles or kilometers and from this we easily get the length of the semi-major axis. This gives us the size of the system. Since we know the angular separation of the components as seen from the Earth, and now their actual distance apart we can at once compute their parallax. Knowing their period and the semi-major axis of their orbit we can derive the value of their combined mass in terms of the mass of the Sun by an extension of Kepler's Third Law. Thus we may determine the distance, size and mass of a binary system.

It will be observed that we simply measure the *relative* motion of the two stars with the spectroscope, hence all proper motion that the system may have as well as the motion of the Earth is eliminated, and it is only necessary to make the observation when the component in the line of sight is as large as possible. This, of course, depends upon the eccentricity of the orbit and the position of the periastron. It is evident, too, that in many cases we shall be able to measure the distances of stars much farther away than by the other methods, since the only condition depending upon the distance is that the components shall be separated widely enough so that we may obtain the orbit by micrometrical measurement. According to the measures of Gill and Elkin with the heliometer the parallax of α Centauri is $0''.75$. If the star were eight times as far away its parallax would just be measurable by this method; but the separation of the components is such that we could get its orbit, and consequently its parallax by the spectroscopic method, if it were eighty times as far away. At present we cannot even conjecture on what scale stellar systems may be formed and to what remote parts of the universe we may extend our geometry. It is not probable that α Centauri is the largest system in the sky

and it may be that as spectroscopic methods are improved in the future we shall be able to determine with precision the distances of stars in such distant regions that hundreds of years are required for their light to traverse the vast space by which they are removed.

Nor is this all. We may also be able to throw some light upon the question of the magnitude of clusters and stellar groups. At present we do not know whether they are large suns and widely scattered, but so far away that they appear small and crowded together, or whether they are relatively small bodies derived from some great, original mass which failed to form a central sun in the process of its evolution. But if we can find a binary star in a cluster or group and can get its orbit we can also get its distance. If it has the same proper motion and is of the same color, magnitude and spectral type as the other stars apparently around it the evidence is almost conclusive that it really belongs to the cluster and therefore we have a scale for the measurement of the whole system.* It seems very probable that these results will to some extent be realized since Burnham has already discovered double stars in several clusters and groups of the northern heavens. If we ever succeed even in one or two cases we shall have a knowledge of the structure of the universe for which we have never before dared to hope.

There is another result of this method which is of the highest philosophical interest. By a series of observations of the relative motion in the line of sight we are able to determine rigorously the nature of the law of gravity in different parts of the visible heavens. In deriving the elements of the orbit of a double star from micrometrical measurements we assume that the motion of the components is governed by Newton's law of gravity. It is necessary to assume the law of attraction since the plane of the orbit is, in general, inclined to us, and we cannot, therefore, determine what part of the real orbit the central star occupies, which must be known in order to find the nature of the central force. It is well understood that where the law is that of the inverse squares the central force occupies one of the foci of the elliptical path of the revolving body. Now, in the apparent binary star orbits the central star does not occupy one of the foci owing to the projection of the ellipse, therefore some other law of attraction may be operating as has been shown by MM. Darboux and Halphen. To test the law of gravity with the spec-

* See article by Dr. See in *A. N.*, No. 3323.

troscope we assume that it prevails in that system, and then derive the elements upon that suppositon. We then make an observation of the relative motion of the two stars towards us; this, as has been before explained, gives us the dimensions of the ellipse. From these data we can compute what the motion will be at any other epoch; we then apply the spectroscope and if the observed motion is the same as the computed, the attraction must be according to Newton's law of gravity since it can readily be demonstrated that no other central force can cause an attracted body to revolve in an ellipse and to have at every epoch the required motion in any direction. In actual practice we would make a series of observations in order to obtain reliable results. While we have considerable reason to suppose that Newton's law governs the motion of the known binaries in every part of the sky, nevertheless, it is of the profoundest interest to know that we can test it by observation and determine whether or not the laws of nature are the same throughout the immensity of the universe.

We might add a word concerning the practicability, at the present time, of the method here outlined. It will be noticed in the first place that the principles employed are well established, both theoretically and practically, although the conditions are somewhat different from those in the work heretofore accomplished. The spectroscope has been extensively used for the measurement of motion in the line of sight by the displacement of the lines of the spectrum. Indeed, quite a number of so-called "spectroscopic binaries" have been discovered in this manner. The lines of the different elements are found to be periodically double and the most natural explanation is that the star is a rapid binary but so close that our telescopes cannot separate the components.

In order for our method to succeed the lines of the spectrum must be sharp and the relative motion of the two stars must be considerable. The motion in the line of sight evidently depends upon both the actual velocity of revolution and the inclination of the orbit. Several thousand double stars are now known of which many are binary systems, and the number is continually increasing. As time goes on and their orbits are determined it seems highly probable that a great many will fulfill all the conditions necessary for the success of the method. The theory is complete and the progress of the past leads us to believe that those instrumental difficulties which may now exist will be overcome in the future. At any rate a method promising such additions to knowledge and results by which the laws and structure

and extent of the universe may be largely determined deserves the most careful attention of scientific men.

THE UNIVERSITY OF CHICAGO,
1896, Jan. 13.

THE PHOTOGRAPHY OF PLANETOIDS, BY PROFESSOR MAX WOLF.

DR. EDWARD S. HOLDEN. (ABSTRACT.)

The *Astronomische Nachrichten* No. 3319 contains an exhaustive paper by Professor Max Wolf, of Heidelberg, on the photography of planetoids, based on his personal experience in the years 1891-1895. His work has been done with portrait lenses of five and of six inches aperture, with foci of twenty-five and of thirty inches, respectively. The lens is kept accurately pointed for exposures of one and one-half, or, better, two hours, and the stars appear as *dots* on the plate, while asteroids are distinguished by their (short) *trails*.

To draw safe conclusions from such observations, the plates must be in duplicate. If both plates are simultaneously exposed, errors on one plate may make the result doubtful. Professor Wolf prefers to expose plate A for one hour, then to begin the exposure of plate B, to close plate A after another hour, and, finally, to close plate B at the end of the third hour. Part of the space occupied by the *trail* of a planetoid on A will be vacant on plate B, and *vice versa*.

If a visual telescope of sufficient power is at hand, the shortest method is to expose one plate only, and to examine the sky with the visual telescope to resolve the doubtful points suggested by the plate. This is the method so successfully followed by M. Charlois at Nice.

An important advantage of this method of research is the wide field covered by the portrait lens.*

For planetoids brighter than 12.6 magnitude, Professor Wolf finds that a field of some seventy square degrees is available under good conditions.

To compare two plates, A and B, both plates are laid on a retouching frame, one over the other, with both films downwards, and are then examined with a hand-glass. This method is found by Professor Wolf, after long experience, to be preferable to

* This point was laid before the International Astro-Photographic Congress by Messrs. E. C. Pickering and Steinheil, but such lenses were rejected for the International Map.

other processes, suggested by Messrs. E. C. Pickering, Barnard, and by Wolf and Lenard.

Whenever it is possible, the R. A. and Decl. of the planet should be obtained from visual observations, and not from plates made with portrait lenses of short focus. If portrait lenses of sixteen inches aperture and eighty-odd inches focus are available (such as the Heidelberg Observatory expects to possess), the case is different, and good positions can be had from the plates. The estimation of the magnitude of the planet from its *trail* requires long experience, and is always difficult. The measurement of positions on photographic plates is attended by a swarm of difficulties, which have been considered in detail by Professor Wolf in *Astronomy and Astrophysics* for 1893, page 799, to which reference is made.

During the past years, Professor Wolf has experimented with all kinds of developers, and concludes that, in respect of the energy of the development, there is little to choose between them. He generally employs *Rodinal* in its commercial form, using ninety parts of water to ten of Rodinal, and not developing too long,—that is, the plate is not allowed to become too dark. By long and careful researches, Professor Wolf also concludes that he can secure somewhat fainter impressions on the plate by a strong developer acting for a short time than by a weak one used for a long development. So-called restrainers, as Sodium-bromide, should not be employed. They produce a clear film, but the fainter impressions are lost.

These remarks relate to the photography of planetoids, etc., and are not applicable to photographs of nebular *details*, etc., to photographs of the Sun and Moon, etc. In such cases the *Glycin* developer is to be recommended, using *fresh* plates. For planetoids and faint nebulæ, old plates and a rapid development are desirable.

From the tables in Professor Wolf's paper, it results that in

1892,	38	known	and	18	new	planetoids	were	found	by him.
1893,	27	"	"	9	"	"	"	"	"
1894,	15	"	"	6	"	"	"	"	"
1895,	19	"	"	3	"	"	"	"	"

or, one new planetoid was found

to	2.1	known	planetoids	in 1892.
to	3.0	"	"	" 1893.
to	2.5	"	"	" 1894.
to	6.3	"	"	" 1895.

It would seem, from this table, as if the number of the unknown planetoids as bright as the twelfth magnitude had been

materially reduced, though it is probably too soon to draw this conclusion.

When one reviews the work that has been done in this field in order to see how far the photographic method of discovering planetoids has succeeded, the result is most satisfactory.

By means of the photographic method, many new planetoids have been discovered, and, what is at least as important, many old planets which had been "lost" have been re-discovered,—which would hardly have been the case had we depended solely on visual observations.

As in other fields of research, it has been found that photography, so far from doing away with the necessity for visual observations, has, in fact, created new demands upon the former methods, and has increased, not dimished, its scope and usefulness.

In a foot-note, Professor Wolf remarks that he feels obliged, on account of the pressure of other work and on account of his present state of health, to abandon the field of the discovery of planetoids by photography. In the four years of his work, he has discovered no less than thirty-six new asteroids, and has rediscovered many of those which were "lost," and he may leave the methods which he has created to other most capable observers, well content with his own contributions to this branch of science. By the time the Heidelberg Observatory obtains its pair of great photographic lenses,* it is hoped that Professor Wolf may be in robust health, and ready to use them in new fields. If there is an unknown major planet, the best hope for its discovery is by these lenses or by the Bruce telescope of the Harvard College Observatory, or by some instrument of like class, with a large field and great light-gathering power.—*Publications of the A. S. P. Nos. 46, 47.*

THE PLANET MARS.

W. W. PAYNE.

During the last few years no one celestial object has occupied the attention of astronomers so fully and so earnestly as has the planet Mars.

Special interest in the study of Mars began in 1877 when Hall of Washington discovered its two tiny satellites and Schiaparelli of Milan, first saw some of its famous canals. Professor Hall's

* See *Publications* A. S. P., Vol. VII, p. 285.

discovery was regarded as an astonishing piece of astronomical observation because the satellites were so small, so far from the Earth and one of them so near to the ruddy planet himself. That any one by the aid of a telescope of any size should discover a heavenly body not more than ten miles in diameter at a distance of over forty millions of miles from the Earth, and at farthest within four thousand miles of the bright surface of Mars and that, too, when the planet was most brilliant is very remarkable. As a piece of work in discovery, it seems to us to rank all before it, and to follow closely the best since in the annals of astronomy. The renowned Schiaparelli was not so fortunate in the estimation of astronomers at first, or even for years afterward; for no one could see the so-called canals of Mars which he had first observed in 1877 and verified more fully and wonderfully in 1879. For in the latter year he not only announced the existence of many canals all over the surface of Mars but he also declared that twenty of these strange and fine-lined objects were certainly double where they had before always appeared single. This was too much for the credulity and the good nature of skeptical astronomers anywhere. All doubted and some indulged in ridicule or criticism. The fact that Schiaparelli with a glass only 8⅓-inches in diameter should see all this detailed marking on the planet's surface and all other astronomers in the world should not be able to see anything of the kind altnough some possessed telescopes many times as large, was truly a ground of most palpable suspicion and very general criticism in regard to the claims of the famous Italian astronomer. For nine years, and until 1886, this heroic discoverer maintained his ground, labored on incessantly and enjoyed alone the visions of the new Martian world which his own patience and perseverence had opened so clearly before him. These years of peculiar loneliness in a new realm of visual truth to-day most woefully shame the boasted cleverness of science so late in the nineteenth century. Perrotin of Nice was the first to break the unhappy spell of outside cavil and turn the tide of the Martian canals in Schiaparelli's favor. This was done by the aid of the great Nice refractor of 29 inches aperture which had been but recently set up. On the 15th day of April, 1886, Perrotin and Thollon both saw the canals unmistakably by the aid of that great telescope, and also saw some of them double substantially as Schiaparelli had drawn them. Some other astronomers have observed these intensely interesting markings on the surface of Mars, and a very few have studied them thoroughly and ad-

vanced our knowledge of them greatly during the last two years.

It is a natural question to ask why it is that all this detailed knowledge of the surface of Mars was not observed by others sooner, especially after its announcement by Schiaparelli. It could not be that his telescope was better than all others, for it was a small one. It could not be that his sharp and trained eye was so much superior to all others, that what he could see well and minutely describe should be wholly invisible to all other observers for a period of nine years after announcement. This question almost more than any other has interested astronomers very greatly of late, and induced thoughtful study of it as never before. The trial of mountain stations for observation, those in regions of quiet, clear air of lower altitude and those of broad high plateaus have all been made, to learn by actual use the best conditions for difficult telescopic work. The planet Mars has recently been in favorable position in regard to distance from the Earth for the study of surface markings, and the opportunity has been most diligently and persistently used by the aid of telescopes of all sizes and in all favorable latitudes for the sake of learning something new and helpful in making astronomical observations that would bring into use the hightest powers of the modern telescope.

Those who desire the sources of best information in regard to what is now known about the planet Mars, and a delightful account of how astronomers have gained their knowledge should read two important books: one by Camille Flammarion, of Paris, published in 1892, and the other by Percival Lowell, of Boston, recently published by Houghton, Mifflin & Co. Flammarion's book was by far the most complete and comprehensive study of Mars that had appeared up to its date. It is indeed a scholarly compendium of what was known of the planet, involving much illustration and great pains-taking in gathering materials. On the other hand Mr. Lowell showed good judgment in not attempting to write another book on the same subject like that of Flammarion, but by the aid of a fine 18-inch refractor he has tried most industriously and effectively to widen the range of knowledge concerning a score of vitally interesting questions chiefly about the physical conditions that exist on the planet Mars. How well he has succeeded in this any thoughtful reader can judge for himself after a perusal of his book which is written in plain popular language, but crowded with an array of facts that are made to signify much that is new by the gifted and ready reasoning power which Mr. Lowell possesses as a writer, in a re-

markable degree. Later we wish to make a careful comparison of his views which are deemed new with those of others bearing on the question of Martian atmosphere, temperature, canals, water inundation, desert regions and other similar features which Mr. Lowell's book discusses.

ALASKA BOUNDARY SURVEY.

OTTO J. KLOTZ.

For Popular Astronomy.

The surveys that have been made during the past three years were not made with the object of defining the boundary line of southeastern Alaska, but for the purpose of gathering data so that the question of delimitation may be more intelligently discussed, prior to actual marking on the ground. The survey was carried on under a joint Commission, W. F. King being Her Majesty's Commissioner, and T. C. Mendenhall, now succeeded by Genl. W. W. Duffield, Superintendent of the Coast and Geodetic Survey, representing the United States.

In 1893 the U. S. Coast and Geodetic Survey had twelve officers in the field, of whom three had charge of parties, three were astronomers and the remaining six were attached to six Canadian survey parties. Canada had seven parties in the field and all engaged in topographic work. There was a Canadian representative, too, on each of the United States Stikine and Taku River parties. Furthermore each country had a vessel for intercommunication between the parties.

The area covered by the Canadian parties during this season included nearly all the territory adjoining the shore line from Burrough's Bay or the Unuk River which empties there, to the west side of Taku Inlet.

The United States parties were engaged in the survey of the Stikine and Taku Rivers and Taku Inlet; and in the determination of the latitude and longitude of the mouth of the Unuk, Wrangell, and the mouth of the Taku. Sitka served as base station for longitude, whence chronometers were carried fortnightly by the United States survey vessel to the three astronomic stations mentioned. In 1894 the operations were continued and extended, and on similar lines. The close of this season left little remaining to be done for the present. Canada had only one party in the field this year (1895), and its work was along the base of the Mt. St. Elias Alps.

Of the methods of work in the field I will only speak of those adopted by Canada.

Knowing beforehand the intensely mountainous character of the country under discussion, it was obvious—based on experience in the Rocky Mountains—that the most practical and cheapest method for a topographic survey was by means of the transit and camera. The idea of the application of the camera for topographic purposes is not new, but its practical application on a large scale is of recent date. Germany, France and Italy have done photographic work, but only the last named country has done any on an extensive scale. However, Canada has done considerably more, and has raised the art from its experimental stage to one of permanency, through the labors of her Surveyor General, E. Deville.

Without following photo-topography through its various stages of development in Canada, we will confine ourselves to a statement of the modus operandi of the Boundary Survey.

The greatest drawback to the progress of the work was the continuous saturated condition of the atmosphere showing itself either as rain, fog or fog banks, and clouds so that the area covered by survey in a season is not a fair estimate of what the parties could have accomplished under ordinary climatic conditions. Many a time did an early morning bode a fair day, when a start would be made from a seashore where camp was almost invariably pitched, for an ascent of perhaps five thousand feet, only to find after hours of scrambling through Devil's Club (Fatsia horrida), knee-deep moss, windfalls, alder brush on land slides; then emerging through timber line onto rock and snow and glaciers with their treacherous crevasses; skirting chasms and abysses, at times with only slender foot-hold to save from the yawning depths; again lying full length with arms extended on smooth, slippery glaciated rock and creeping along, onward—upwards to the goal, and when reached, oneself enveloped in a bank of clouds hovering around the peak and completely shutting out the world. Perhaps it will lift is the ardent hope. One waits, shivers. At times it snows to add to the discomfort, often misery. In vain, the day advances, the Sun is seeking its western home, and with faint heart the party has to begin the descent. It is made more quickly than the ascent but often with more danger, as the men indulge in the expeditious method of glissade—sliding on the ice or snow crest with the imminent danger of a crevasse or precipice. But camp, like the word home, has a magic and magnetic spell. Almost nothing save destruction stops the powerful attraction.

However disheartening such work is, success can only be accomplished by working until one does succeed. Hence many a mountain peak was climbed more than once, one in fact eight times. Success is good natured and immediately forgets all previous trials and tribulations. The season of 1893 did not give a dozen really good days for instrumental and photographic work.

A good view from a peak has been aptly described by

> "What a scene of desolation
> I saw from the mountain peak;
> Crags, snowfields, glaciation,
> Unutterable to speak."

The shore line of the northwestern part of the continent is very much indented by bays, inlets and fiords or canals. Adjoining the sea the vegetation is rank, and the luxuriant mosses and ferns give it a semi-tropical appearance. Timber line is reached at about 2,500 feet. The forest is almost exclusively coniferous.

Nearly the whole of the shore of the territory under consideration has been surveyed and charted by officers of the United States Navy, and this, in a measure, served as a base for the topographic work. However, each party measured, by means of steel tape, a base line at some known point on the shore, and from it expanded a triangulation over the area whose topography was to be delineated. It is scarcely necessary to state that for mountain work everything must be made as portable as possible, and instruments reduced to a minimum of weight.

The outfit of each party consisted of a Troughton & Simms 3-inch transit theodolite in a leather covered box and carried like a knapsack; an extension tripod; a camera, to be described more fully hereafter; several aneroids by Hughes; a sidereal chronometer; a field glass, and one or two box compasses; and each man was provided with the indispensible alpenstock. For transport each party was supplied with one Mackinac boat, which served its purpose admirably, and one or two Peterborough canoes, those marvelous water sprites that dance on rapids or on the ocean billows with a steadiness wonderful. I recollect one of of our American friends thought them at least "cranky" looking and had some hesitation in getting into one of them, saying that for safety he ought to have his hair parted in the middle.

Both the horizontal and vertical circles of the transit read to minutes of arc. Angles were read in the usual way, *i. e.*, one set —circle right; the other—circle left. The sides of the triangles were mostly between six and ten miles, although distant peaks were tied by sides upwards of forty miles long, and St. Elias by

lines over sixty miles long. It may be stated right here that the photographs of these latter distances came out sharp and clear and flat, and were hence available for outline topographic purposes. At each station horizontal and vertical angles were read on all the principal peaks and points in the terrene. From the horizontal angles the triangulation or skeleton, upon which the topography is based, is obtained; and from the vertical angles the heights of such peaks, which are later checked by the photographs themselves. As some of the peaks occupied were isolated, sharp and well defined, signals or cairns were not placed at all the summit stations. The azimuth was controlled by solar observations when obtainable. Stellar observations were impracticable at mountain stations, although some were taken at sea shore.

As the camera is the characteristic instrument of the Canadian Survey, a somewhat detailed account of it will be given. As before intimated, the camera, in its present form, is the outcome of yearly experiments and experience since its first application by Canada in the Rocky Mountains in 1886.

The first distinctive feature about the camera is that it has no focusing adjustment, as all views taken are distant, the rays are practically parallel and converge at the same distance from the lens. The camera box is therefore very rigid, of well seasoned mahogany and brass bound. For use it is attached to a brass foot with levelling screws, and held by a stout screw, with milled head, passing through the middle of the foot, and into a brass block in the box. The foot itself fits onto the transit tripod, the latter serving for both instruments.

As it is essential that the camera be horizontal, it is provided with two levels in the form of a T, attachable to a brass grove on top of the box. In the middle of each side and directly in front of and close to the sensitive plate is fixed a narrow (⅛″) brass comb. The four are consequently photographed on each view, and serve the purpose of readily drawing the horizon and principal lines on the photograph or enlarged print, for these are the lines of reference or axes of coördinates for interpreting the prints. Each camera is provided with six double holders, numbered and carrying a dozen glass plates, which are generally sufficient for a day's climb. The plates are 4¾ x 6½″, isochromatic and made by Edwards, London. The plates before being put into the holders are marked in one corner with consecutive numbers, together with the initial of the chief of party, and a note is made of the corresponding number of the holder, so as to be able

to enter in the field book, when exposing, the number of the negative, its corresponding station and view. Each party was provided with a small black tent, lined with red, and a red light lantern for changing plates. The tent was just large enough to admit one, and was generally suspended from the ridge pole in one of the camp tents and overhanging the small camp table, so that the changing could be done with ease and comfort. There being really no night in midsummer in Alaska, it would scarcely be safe to change in an ordinary tent, even at midnight. The camera could also be set on end on the tripod. This was for the purpose of being able to photograph deep ravines or cañons where the vertical element exceeded the horizontal.

The lens or objective is a wide angle one by Dallmeyer, London. Between the two lenses forming the objective is inserted the diaphragm or stop. Of those supplied with each camera, the smallest one ⅛″ is always used. The focal length of the lens is 5⅜″. The lens screws onto the detachable front piece of the camera, and when not in use is carried in a leather case. In screwing it in place it is always brought up to the mark cut on the collar so as to preserve a uniform distance from the sensitive plate.

(TO BE CONTINUED.)

NOTE.—For giving an idea of the country in which the work was carried on, and also of the result of photographing distant views the reproduction of photographs is given as frontispiece.

One of our grandest views is that of photographs covering parts of the vast complex of the Muir Glacier System.

On view No. 1 will be noticed the comb marks in the middle of the sides. The two straight lines joining the proper points on opposite combs constitute the axes of rectangular co-ordinates for measurements on the photograph. This view is taken from an elevation of 5913 ft. The station is situated between the two main branches of the Baird Glacier emptying into the northern part of Thomas Bay, Frederick Sound. The pointing of the camera is southeasterly, across the eastern branch and along one of its affluents onto the Devil's Thumb, (shown on left hand side) 9105 ft. high, and distant sixteen miles. Most of the other mountains shown are more distant, some over thirty miles.

Comparing this photograph with ones taken about Borrough's Bay—in general with those of the more southerly areas where the heights are mostly confined to heights of less than six thousand feet—a marked contrast is noted and that is, that mountains of less than the latter height are invariably rounded showing no sharp pinnacles or peaks, while those to the north, exceeding such height, have very angular and sharp crests. The former have been subject to glacial abrasion, the latter not, *i. e.*, not above say six thousand feet.

View No. 2 is from a station, altitude 4,881 ft., on the east side of Thomas Bay, and looking northeasterly, also showing the shaft of the Devil's Thumb. This station with the preceding one and the Devil's Thumb form approximately an equilateral triangle of 16-mile sides. It will thus be seen that these two views

intersect each other and have numerous points in common, which the expert photo-topographer readily identifies and transfers to the map.

Ottawa, Canada.

THE GRAPHIC CONSTRUCTION OF ECLIPSES AND OCCULTATIONS.

III.—Occultations.

WM. F. RIGGE, S. J.

For Popular Astronomy.

An occultation is an eclipse of a star or planet by the Moon. It differs from a solar eclipse mainly in this, that the star is a mere point at an infinite distance, and that as a consequence, the Moon in intercepting its light casts no penumbra, but only a perfectly cylindrical shadow, whose cross-section is everywhere equal to the Moon's disk. We can therefore plot an occultation in the same way as a solar eclipse, so that this article will offer no special difficulties; on the contrary, many things will be simplified, though, of course, there are certain technicalities with which we must become acquainted. As occultations occur so frequently, sometimes a dozen in a day, they offer greater inducements to study than solar eclipses. But before we can begin the construction of a practical example, we must premise a few remarks about the Ephemeris, and with its help make some preliminary tests of the visibility of an occultation at a given place.

Preliminary Tests of Visibility. In the Ephemeris from page 418 to 451 we shall find the "Elements for the Prediction of Occultations" for the Earth generally. We shall notice that the pages are divided by two heavy lines into three main columns, two of which are about equal in width, and the third is very narrow. Each of these main columns is subdivided into smaller ones.

The main column to the left gives the names of the stars to be occulted, their magnitudes, their reductions to apparent place (which we shall not need for our work), and their declinations. The second main column is entitled "At Conjunction in Right Ascension," and gives the Washington (local) mean time of this conjunction of the Moon and star as seen from the Earth's centre, the Washington hour angle, H, of the Moon and star at that moment, and the values of Y, x' and y', which we shall explain presently. The last column is entitled "Limiting Parallels" of latitude outside of which the occultation will not be visible.

An occultation to be visible at a given place must fulfil three conditions, as the Ephemeris remarks on pages 520 and 521. The first of these depends upon the latitude, the second upon the longitude and the third upon the physical circumstances of visibility.

First, the limiting parallels in the last columns must include, and we may add, liberally include, the latitude of the place. But if the reader will take the trouble to turn back to Fig. I given in our last article on solar eclipses, he will see that although the penumbra extends far north of the latitude of St. Louis at the middle of the eclipse, yet if the Moon's transit across the Earth's disk were delayed six hours so that its center should be at X1 on its path when St. Louis was at V on the ellipse, the eclipse would not be visible at St. Louis at all, because the penumbra would not extend to that point, while other places far to the west of St. Louis on the same parallel would see the Sun eclipsed to a considerable degree. This first condition is therefore not sufficient, but we must apply the others as well.

Secondly, if λ is the longitude of the place west of Washington, the quantity $H - \lambda$ taken without regard to its sign, that is, whether the algebraic difference of H and λ be plus or minus, must be less than the semi-diurnal arc of the star by at least one hour: which means in other words that the star must be an hour above the horizon whether after rising or before setting, in order that haze near the horizon may not interfere with the observation. This semi-diurnal arc, or the time it takes the star to travel from the horizon to the meridian or from the meridian to the horizon, is for the latitude of the middle of the United States about 7¾ hours for the declination $+30°$, 7 hours for the declination $+20°$, 6½ hours for $+10°$, 6 hours for $0°$, 5½ hours for $-10°$, 5 hours for $-20°$, and 4¼ hours for $-30°$, or about half an hour more than six hours for every ten degrees of north declination, and as much less for south declination.

Thirdly, the occultation must not occur during the day time, except when the Sun is low and the star very bright, and a telescope is used. This third condition we must in practice restrict still more: we would like the occultation to occur in the early hours of the night, and with the crescent moon. We would also prefer a very bright star. This last however, is not essential, because a small telescope will show the occultation even of a sixth magnitude star very well if the Moon is not too bright.

Selecting an Occultation. Bearing these three conditions in mind, we examine the long list of occultations. We need not be

deterred by its length, as whole pages may at times be disposed of in a few seconds. The best condition to apply first is the third one. We run down the column headed "Washington Mean Time" until we come to an hour that suits us (we should not forget to subtract our longitude if it is large). Or we may first run down the column of magnitudes. A glance at the limiting parallels will often unpleasantly disappoint us. If our star stands these tests, we look at the column H and form $H - \lambda$. Our last hopes will often be shattered here. It is surprising how very few occultations we can pick out of the vast number given in the Ephemeris. However, if the amateur has ever observed the occultation of a first magnitude star or of a planet, especially of Jupiter or of Venus, by the crescent Moon in the early hours of the night, he will be willing to wait patiently for a whole year to witness such a phenomenon again, especially if everything succeeded according to his prediction.

Let us apply these tests to τ Scorpii on August 16, 1896, for St. Louis. The Washington mean time of conjunction (Ephemeris, p. 437) is $8^h\ 18^m$. As St. Louis is $0^h\ 53^m$ west of Washington, the St. Louis time of conjunction is therefore $7^h\ 25^m$ P. M., a very convenient hour. As the Sun sets on that day at $6^h\ 52^m$, and the star is of the third magnitude, and the Moon eight days old, the third condition is satisfactorily fulfilled. The limiting parallels $+ 62°$ and $+ 22°$ certainly include the latitude $38° 38'$, and liberally too. H is $+ 1^h\ 32^m$ and $H - \lambda = + 0^h\ 39^m$, the star is therefore less than an hour from the meridian. All conditions are consequently fulfilled, and we may begin the construction.

Plotting. The large semicircle in Fig. I represents the northern half of the Earth's disk as seen from the star, τ Scorpii. The radius of this disk is as usual unity. The axes of X and Y, the fundamental plane, the projection of the path of St. Louis into an ellipse, and the like, are the same as for a solar eclipse. As the declination of the star is negative, $\delta = - 28° 0'$ (Ephemeris, p. 437), the ellipse is tilted upward, and the part visible from the star is less than half, the semi-diurnal arc being only about 4¼ hours. The semi-major axis is $a = \cos \varphi = 0.782$, the semi-minor axis, $b = a \sin \delta = \cos \varphi \sin \delta = 0.367$, and the distance of the center of the ellipse from the center of the disk is $d = \sin \varphi \cos \delta = 0.548$. The positions of St. Louis for every hour are plotted in the manner given in our last article.

The Moon's path is laid down in a manner exactly similar to that used in lunar eclipses, that is, by means of one known point in it and its known direction. This known point is G where the

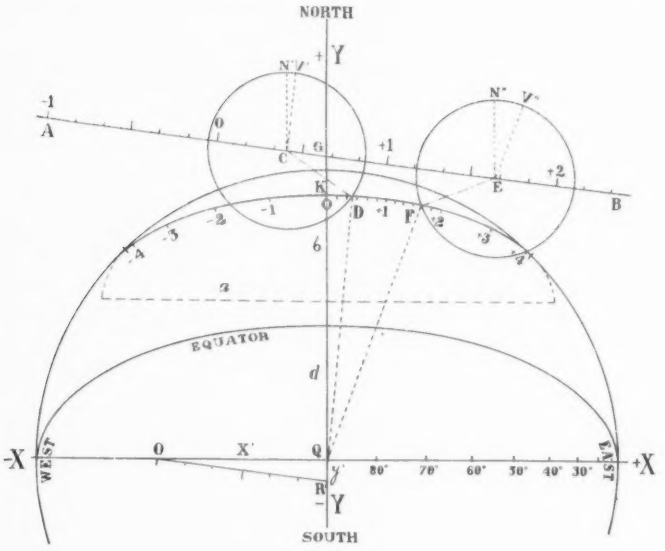


Fig. I.

path cuts the axis of Y. The distance QG is given by the Ephemeris (p. 437) and called Y. It is equal to + 1.052. The direction is found by recombining the decomposed hourly motions of the Moon in right ascension and declination. These motions are computed by the Ephemeris, for our express convenience on the scale we are using. They are, in right ascension $x' = 0.582$, (always positive because the Moon's motion is always eastward or toward the positive end of the axis of X) and in declination $y' = -0.076$. We lay off $OQ = x' = 0.582$, always to the left or west of the center Q in order that we may be able to lay off $QR = y' = -0.076$ on the axis of Y up or down according to its sign. Laying off the value of x' to the left instead of to the right as its sign would lead us to expect, avoids the use of a second pair of dividers and prevents all misunderstanding as to the direction of the Moon's motion. From O to R is in direction and amount the Moon's hourly motion in its orbit as seen from the star. We at once divide OR into sixths or 10 minute spaces, to use as our measuring staff in locating the Moon on its path AB, which we draw through G parallel to OR. But before we can graduate the line AB, we must know where the Moon is at the beginning of an hour.

If we were plotting a solar eclipse, we would say that St. Louis is at K on the axis of Y at local apparent noon when the Sun is on its meridian, and that its hourly distances from K on its ellipse are expressed in apparent solar time or in solar hour angles. Hence, applying this to our occultation in which τ Scorpii replaces the Sun, we say that St. Louis is at K when the star is on its meridian, or at the moment of the star's transit, and that its hourly distances from K on its ellipse are expressed in stellar hour angles. Knowing the position of St. Louis, therefore, at the time of the star's transit and at any time before and after, we must find one position of the Moon at a known stellar hour angle. Such a position is the point G on the axis of Y, where the Moon is to be found at the time of its true conjunction with the star as seen from the centre of the Earth. At this moment of true conjunction, when the Moon and star have the same right ascension and the same hour angle, their common hour angle at St. Louis is $H - \lambda = + 0^h\ 39^m$, as we saw before when we applied the tests of visibility to this occultation. As the Moon's motion is always from west to east, we lay off towards the west from G 39^m from our scale of hourly motion OR, and call the point to which this brings us 0^h. Starting from this point we lay off by successive applications of our measuring staff, OR, the Moon's position at other moments.

Times of the Phases. Remembering that in occultations the Moon's shadow is of the same cross-section as its disk, we shall easily see that the Moon's shadow will overtake St. Louis on the diagram, that is, the star will disappear at the Moon's limb, at the instant when the distance between St. Louis and the centre of the shadow is equal to the latter's (or the Moon's) semi-diameter, 0.272. With the dividers, therefore, opened to 0.272 we find two points, one on each path, which show equal times. These are the points C and D, and both read $+ 0^h\ 25^m$. This is the moment of immersion. Similarly, for the reappearance of the star, or the emersion, we find, with the same opening of the dividers, two points which show equal times. They are E and F both reading $+ 1^h\ 39^m$. These times, as was said before, are stellar hour angles, that is, hour angles of the star at St. Louis at the moments of immersion and emersion: if minus, they show that the star is east of the meridian, and if plus, that it is west.

These stellar hour angles are now to be changed to local mean or standard time. The Ephemeris gives on page 437 the Washington (local) mean time of conjunction as $8^h\ 18^m$. We subtract algebraically from this the quantity H of the Ephemeris and call

the result, $6^h\ 46^m$, the St. Louis (local) mean time of transit or that corresponding to the moment 0^h of our diagram. We add to this algebraically $+\ 0^h\ 25^m$ and $+\ 1^h\ 39^m$, the local hour angles we have found for immersion and emersion, and we have $7^h\ 11^m$ and $8^h\ 25^m$ as the local mean times of these phenomena, or in Central time $7^h\ 12^m$ and $8^h\ 26^m$.

The value we have used for the St. Louis time of transit is not quite correct, on account of the difference of value of an interval of time when measured in mean and sidereal time. But the final quantities are less in error and will not be wrong by more than a small fraction of a minute, a quantity too small to be practically of account for us.

Position Angles. In order to obtain the angular distances from the north point and from the vertex of the points of disappearance and reappearance of the star at the Moon's limb, we draw the lines CN′ and EN″ through the Moon's center parallel to the axis of Y, and the lines CV′ and EV″ through the Moon's center parallel to the lines DQ and FQ which join St. Louis on its ellipse and the center of the Earth's disk. The first lines will give the Moon's north point N′ and N″ and the second the vertex or uppermost point V′ and V″. These lines are, of course, to be drawn on the Moon, because the star is a mere point and cannot have position angles marked on it as the Sun can, and hence we must be careful to draw the lines CV′ and EV″, which determine the Moon's vertex, parallel to the lines QD and QF, and not directly through Q and the Moon's center. These position angles on the Moon's disk are then by measurement found to be, for the immersion, N 128° E or S 52° E, and for the emersion, N 110° W or S 70° W. The angles from the vertex are V 123° E and V 131° W, and the parallactic angles N′CV′ and N″EV″ are 5° and 21°. The position angle at the immersion need not be known, because the star itself, except when very faint and near the full moon, renders this unnecessary, but it is indispensable at the emersion, when this occurs at the bright limb, and is convenient in any case.

Moon's Altitude. As a knowledge of the Moon's altitude may be useful, we may measure it on the diagram in the usual way, that is, by measuring QD and QF on our scale, and in a table of natural sines finding the arcs of which these measured values are the cosines. Thus by measurement, QD = 0.919, and QF = 0.943; they are the cosines of 23° and 19½°. These are the altitudes of the star, strictly speaking, but the Moon's centre can never be more than a quarter of a degree away. Nothing depends upon an exact knowledge of the altitude, it is merely a matter of con-

venience or curiosity. If we construct, once for all, on the edge of a piece of stiff paper, a scale of altitudes such as is to be found on the diagram on the right side of the axis of X, reading the altitudes will be a matter of a few seconds. The construction of this scale will probably not require any explanation, as the distance from Q of any number such as 70° is the cosine of 70°.

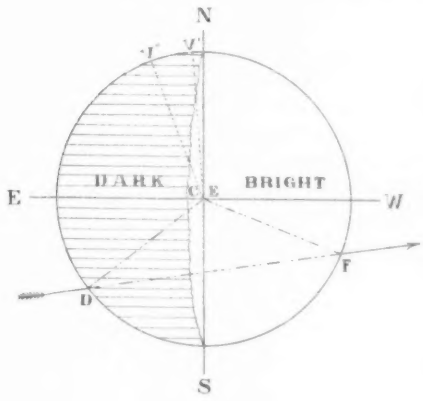


Fig. II.

Field Diagram. For the sake of greater convenience we may gather in and under another small diagram, which we may call a "field diagram" to be used at the time of the occultation, all the information furnished by our work. Such a one is Fig. II. The circle represents the Moon's disk drawn to any size whatever, in fact, the radius may be entirely unknown. On it we lay off the cardinal points, taking care of course to put W on the right hand.

Occultation of τ Scorpii.
August 16, 1896.
St. Louis, Mo.

Immersion.		Emersion.
$+0^h\ 25^m$	Star's Hour Angle	$+1^h\ 39^m$
7 11 P. M.	Local Mean Time	8 25 P. M.
7 12 "	Central Time	8 26 "
	Star's Transit	6 46 "
	Sun set	6 52 "
23°	Moon's Altitude	$19\frac{1}{2}°$
	Duration	$1^h\ 14^m$
N 128° E	Position Angle	N 110° W
S 52 E		S 70 W
V 123 E	Angle from Vertex	V 131 W
N 5 E	Position of Vertex	N 21 E
	Moon 8 days old	

Then we lay off the angular distances of the vertices V′ and V″ and of the points of immersion and emersion D and F. If we imagine the Moon stationary and the star in motion, its path behind the Moon's disk is the line DF. Strictly speaking, this line is not straight, but there is no object in determining it exactly. In fact, there is no need of drawing the line at all. We ought to mark the dark and bright limbs of the Moon and shade

the dark part in some way, so that if we should forget to hold the paper with the vertices on top, the shape of the Moon on our drawing may be a guide to us. This may at times be necessary when we use an inverting telescope, especially one with a diagonal eyepiece. For this reason it is well to mark the position angles at the immersion when the star is yet visible, in order that we may know what to do at the emersion and where to expect the star to reappear. The wavy line running from N to S in our diagram is the terminator, which divides the dark and bright portions of the disk. It does not always pass through the north and south points, but is generally very near them. Its exact determination requires more computing than is consistent with our purpose. Its path across the disk is best drawn by estimation, based upon our acquaintance with the Moon's appearance throughout the lunation. In this occultation the Moon is 8 days old, or 1 day 5 hours past the first quarter, when the terminator would be a straight line bisecting the disk.

Duration. There is no such thing as the magnitude of an occultation, because it is always total. However, in place of it we have the duration, the time the star remains hidden behind the Moon. This is evidently equal to the difference of the times of the phases: in our case it is $8^h\ 25^m - 7^h\ 11^m = 1^h\ 14^m$.

Construction for another Place. There are the usual two changes to be made in constructing this occultation for another place. A change of latitude will require an entirely new ellipse. A change of longitude will change the reading $(H - \lambda)$ of the point G, without, however, changing the line AB or the scale OR. The times of the phases, the duration, position angles and altitudes will of course differ from those at St. Louis.

Accuracy. If care has been exercised in plotting, our times ought to be within a minute of the truth. If we require the times more accurately than this, they can be found by the method of computation given in the appendix to the Ephemeris, pp. 514-518. This method, however, calls for a preliminary computation in order to find the approximate times of immersion and emersion, and this preliminary computation can be advantageously replaced by our graphic construction, and that for two reasons. First, on the score of greater accuracy. For, the numerical method supposes the place of observation to move with uniform velocity on a tangent to the ellipse during the interval between a certain assumed time and the true time of the phase. When this interval is large, and when the place is at a considerable distance from the extremity of the minor axis, that

is, when H—λ is large, this assumption may necessitate a second computation before the error of the computed time is reduced to less than one minute. Secondly, on the score of saving time. This will be evident to anyone that has tried both methods. And it will be still more evident, when we have prepared the materials for the graphic construction of all the occultations visible at our place of observation, by the rapid method to be detailed in a later article of this series.

GEORGETOWN COLLEGE OBSERVATORY,
Washington, D. C.

NEW PHOTOGRAPHIC DISCOVERY.—THE SOLAR CORONA PHOTOGRAPHED IN DAYLIGHT. CHIEF CHARACTERISTIC OF THE CORONA.

D. E. PACKER.

From innumerable experiments made during the last six months it has been found that metallic plates, foils and films are relatively transparent to solar radiance of high refrangibility, and that photographic plates screened by such media during exposure to direct sunlight are affected in proportion to the thinness and celestial conductivity of the interposed screen.

This important discovery has been successfully employed in photographing the solar corona. The results obtained are so remarkable and the recorded changes so great and rapid that great caution had to be exercised till a sufficient mass of confirmatory evidence could be obtained to justify this announcement. The photographs secured range from 1895, July 3 to Dec. 15, on which latter date Comet Perrine is also shown very close to its calculated place.

The earlier photographs were principally taken with a camera of 4-inch aperture, the metallic screens employed being tin and lead foil and sheet copper. Prominent equatorial extensions over the regions of active sunspot groups are the chief features of these pictures.

An immense advance was made by the introduction of a small clear aperture (pin hole) in place of the camera lens. As expected a far greater mass of detail, more sharply definite and exhibiting a considerably greater extension of corona was obtained by this method. Generally three or four exposures by both methods, and through different media were obtained on the

same date, and the more prominent details invariably found to agree; a proof of the objective reality of the phenomena.

A preliminary discussion of the photographs seemed to disclose the following characteristics:

1. A very close and intimate connection with contemporary sunspots and sunspot groups—active sunspots, especially when near the Sun's limb indicated by enormous radiations over the particular region of activity. It may be regarded as an axiom that "every sunspot has its coronal ray," as every prominent radiation may be easily assigned to its particular spot, to which it invariably points.

2. That the well known typical spot-maximum and spot-minimum coronal phases alternate pretty rapidly, apparently synchronizing with observed phases of short period spot activity and quiescence.

3. That many of the most prominent radiations exhibit a decided helical structure, two or three convolutions, in some instances being distinctly traceable—a surprising and unexpected feature.

4. The great photographic strength of the coronal rays as compared with the feeble image of the solar disc in the photograph.

5. That the corona is an electrical phenomenon. The remarkable association between sunspots and coronal radiations is, perhaps, the most important feature of the research. If, as appears, we are able to associate particular sunspots with their coronal rays, and study the variation of both at the same time, an immense advantage will have been gained. The research is one that appeals to every student of solar physics and as it can be pursued by simple and inexpensive means, we may safely predict a rapid increase in our knowledge of the Sun's immediate surroundings in the near future.

SOUTH BIRMINGHAM, England.

THE LUNAR EPHEMERIS.*

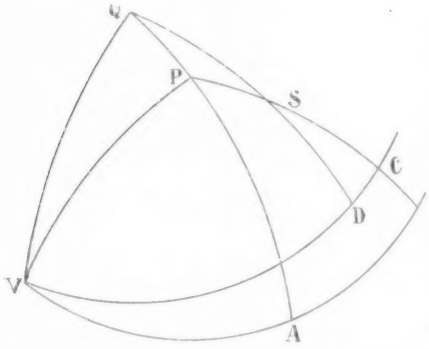
J. MORRISON, M. A., M. B., PH. D.

FOR POPULAR ASTRONOMY.

On pages 272-275 are tabulated the Moon's true longitude and latitude for every mean noon and midnight. The other coördinate—the true distance—is not given but instead of it the equator-

* Continued from page 92, No. 22.

ial horizontal parallax is tabulated on page IV of each month. These coördinates are derived directly from Hansen's Lunar Tables, are fundamental and constitute the basis for all subsequent calculations on the Moon. They are transformed into R. A. and Decl. by the usual formulæ of which the following is a demonstration:



Let VA represent the equator, P its pole, VC the ecliptic and Q its pole, S the position of the Moon or any other celestial body, and let λ and β denote its longitude and latitude respectively. The longitude of the pole of the equator is 90° and the right ascension of the pole of the ecliptic is 270°, therefore in the diagram we have $PQS = \lambda - 90°$, $QS = 90 - \beta$, $PQ = \omega$, the obliquity, $SPQ = 270° - \alpha$ and $PS = 90° - \delta$, of which λ, β and ω are given to find α and δ, that is we have two sides and the included angle of a spherical triangle given to find the other side and one of the other angles. The parallactic angle PSQ is not required. Applying the fundamental formulæ of spherical trigonometry to this triangle we find

$$\sin \delta = \cos \omega \sin \beta + \sin \omega \cos \beta \sin \lambda$$
$$\cos \delta \sin \alpha = -\sin \omega \sin \beta + \cos \omega \cos \beta \sin \lambda$$
$$\cos \delta \cos \alpha = \cos \beta \cos \lambda$$

Dividing the second and first of these, by the third we have respectively,

$$\tan \alpha = -\frac{\sin \omega \tan \beta}{\cos \lambda} + \cos \omega \tan \lambda$$

and

$$\tan \delta = \cos \alpha \left(\frac{\cos \omega \tan \beta}{\cos \lambda} + \sin \omega \tan \lambda \right) \quad (23)$$

These formulæ can be computed in this form by addition and subtraction logarithms and this is the way they have been hitherto computed for every mean noon and midnight in this special case, and then interpolated for intermediate hours. To adapt them to ordinary logarithmic computation, put

$$\sin \lambda = m \cos \varphi$$

and

$$\tan \beta = m \sin \varphi$$

that is

$$\tan \varphi = \frac{\tan \beta}{\sin \lambda}$$

and we readily find

$$\tan \alpha = \frac{\cos (\omega + \varphi)}{\cos \varphi} \tan \lambda$$

and $$\tan \delta = \sin \alpha \tan (\omega + \varphi) \qquad (24)$$

This is the most convenient form, α and δ being determined by their tangents.

The difference of R. A. and Decl. for one minute is computed by (15) and the semi-diameter by the well known relation between the parallax π and the semi-diameter (d), thus

$$\frac{d}{\pi} = 0.272274 \qquad (25)$$

to which 2″.5 are added for irradiation.

Greenwich Transit.

On page IV of each month there are given mean time of transit at Greenwich and the Moon's age at mean noon.

At the time of transit the Moon's R. A. is equal to the sidereal time. Let Θ = the sidereal time at preceding Greenwich mean noon; α = the Moon's R. A. at the same instant and m = the hourly variation of the Moon's R. A. as found on pages V-XII of each month then $.99727m$ = the variation of R. A. in one *sidereal* hour, and if t_s denote the number of sidereal hours from preceding mean noon till the transit, we must have

$$.99727m\, t_s + \alpha = \text{Moon's R. A. at transit} = \Theta + t_s$$

whence $$t_s = \frac{\alpha - \Theta}{1 - .99727m}$$

or in mean solar hours

$$t_m = \frac{\alpha - \Theta}{1 - .99727m} \times .99727$$

$$= \frac{\alpha - \Theta}{3609.856 - m} \qquad (26)$$

where $\alpha - \Theta$ and m are expressed in seconds. This will give only an approximate time of transit since m does not remain constant. A small correction to t_m is therefore necessary and can be found as follows:

Compute from the Ephemeris the values of α and Θ for this approximate time or for the nearest hour and let $\Delta\alpha$ be the increase per *minute* in the Moon's R. A. Now in one minute of mean time the sidereal time increases by $60^s.164$ and if τ denote the correction to t_m we shall have

$$(60.164 - \Delta\alpha)\,\tau = \alpha - \Theta$$

whence

$$\tau = \frac{\alpha - \Theta}{60.164 - \Delta\alpha} \qquad (27)$$

EXAMPLE.—Find the time of Moon's transit at Greenwich 1895, July 4.

To find the approximate time by (26) we have

July 4, mean noon	$\alpha =$	16^h	44^m	$45^s.83$	page 114
" " " "	$\Theta =$	6	48	58 .75	" 111
	$\alpha - \Theta =$	9	55	47 .08	

$$= 35747.08 \text{ sec.}$$

$m = 2.3863 \times 60 = 143.178$ sec. $\qquad 3609.856 - m = 3466.678$

hence

$$t_m = \frac{35747.08}{3466.678} = 10^h.3116$$

$$= 10^h\ 18^m.696.$$

The Ephemeris gives $10^h\ 18^m.8$. On page 114 we see that m varies quite rapidly, being 2.3955×60 at 10 hours. To find the correct time we have

July 4, 10^h	$\alpha =$	17^h	8^m	$40^s.91$
" "	$\Theta =$	16	50	37 .31
	$\alpha - \Theta =$		18	3 .60 = 1083.60 sec.

and $\quad 60.164 - \Delta\alpha = 60.164 - 2.3955 = 57.7685$ sec.

hence

$$\tau = \frac{1083.60}{57.7685} = 18.7575 \text{ min.}$$

which added to 10 hours gives mean time of transit July 4, $10^h\ 18^m.7575$ or $10^h\ 18^m.8$ as in Ephemeris. When four or five consecutive transits have been computed, the date of the next can be anticipated with sufficient accuracy to supersede the necessity of making a second computation.

The column "Diff. for 1 hour" is computed by (15). The Moon's age at noon is found by subtracting the date of the preceding new moon from the given date.

Moon Culminations at Washington.

By means of the Greenwich transit and the hourly variation we can find an approximate date of the Washington transit and then compute a more accurate date by (27) and after having found the correct date of the transit, the R. A. Decl. equatorial horizontal parallax and semi-diameter are interpolated for this date.

An example will best illustrate the process. Find the time of transit at Washington, 1895, April 4.

From the Greenwich transit we find the approximate time of the Washington transit to be $8^h\ 4^m + 2^m.34 \times 5.136 = 8^h\ 16^m.0$ or $13^h\ 24^m.2$ Greenwich time, say $8^h\ 15^m.8$ Washington time or $13^h\ 24^m$ Greenwich time for convenience of interpolation.

Compute α and Θ for this date, thus

1895, April $4^d\ 13^h\ 24^m$

$$\begin{aligned} \alpha &= 9^h\ 8^m\ 20^s.636 \\ \Theta &= 9\ \ 8\ \ 12\ .097 \\ \hline \alpha - \Theta &= \qquad +\ 8\ .539 \end{aligned}$$

We also have

$$\Delta\alpha = 2.3888 \text{ and } 60.164 - \Delta\alpha = 57.7752$$

therefore $\tau = +\ .14779$ minutes

hence Washington time of transit $= 8^h\ 15^m.8 + 0^m.14779$
$= 8^h\ 15^m.95$

and $\tau\Delta\alpha = 0.352$ sec. $\quad 60.164\tau = 8.892$ sec.

therefore $\alpha = \Theta = 9^h\ 8^m\ 20^s.989$

which proves the accuracy of the result. For this date interpolate the values of the Decl. and parallax and compute the semi-diameter from (25) which are respectively $+\ 19°\ 51'\ 6''.9$, $59'\ 50''$ and $16'\ 20''$.

Sidereal Time of the Semi-Diameter Passing the Meridian.

This is computed in the same way as in the case of the Sun, thus let $d =$ semi-diam. and $\Delta\alpha =$ the increase of the Moon's R. A. in one minute of mean time, then in one minute of sidereal time, the increase is $\frac{\Delta\alpha}{\mu}$ where $\mu = 1.00273791$ (page 31) and in the same time the meridian moves 60 seconds. And if t_s denote the number of sidereal seconds in which the semi-diameter passes the meridian we shall have

$$t_s = \frac{60d}{15\left(60 - \frac{\Delta\alpha}{\mu}\right)} = \frac{4d\mu}{60\mu - \Delta\alpha}$$

$$t_s = \frac{4d\mu}{60.164 - \Delta\alpha},$$

when the Moon is on the equator, and for any declination δ, we have

$$t_s = \frac{4d\mu \sec \delta}{60.164 - \Delta\alpha} \qquad (28)$$

If we put

$$\frac{4\mu}{60.164 - \Delta\alpha} = A,$$

we can form a table of values of A with $\Delta\alpha$ as an argument and (28) may be written

$$t_s = Ad \sec \delta \qquad (29)$$

The values of A will be found in Table I.* In our example we have, $d = 980''$, $\delta = 19° 51' 6''.9$ and $\Delta\alpha = 2^s.3888$, and Table I gives $\log A = 8.84150$ from which we find $t_s = 72.336$ seconds.

VARIATION OF MEAN TIME OF TRANSIT AND THE MOON'S MOTION IN R. A. AND DECL. IN ONE HOUR OF LONGITUDE.

Let $\Delta\alpha$ and $\Delta\delta$ denote the Moon's motion in R. A. and Decl. in one minute of mean time (see pages V-XII of each month), then in the same time the meridian approaches the Moon by $60^s.164 - \Delta\alpha$ and if $\varkappa$ denote the interval in minutes in which the Moon passes over one hour of longitude we have

$(60^s.164 - \Delta\alpha)\ \varkappa = 1$ hour $= 60^2$ seconds,

therefore

$$\varkappa = \frac{60^2}{60.164 - \Delta\alpha} \qquad (30)$$

hence the retardation in 1 hr. of long. $= \dfrac{60^2}{60.164 - \Delta\alpha} - 60$ (31)

and therefore we have

Moon's motion in R. A. in 1 hr. of Long. $= \dfrac{60^2\ \Delta\alpha}{60.164 - \Delta\alpha}$ (32)

and Moon's motion in Decl. " $= \dfrac{60^2\ \Delta\delta}{60.164 - \Delta\alpha}$ 33)

The values of (30), (31) and (32) are tabulated in Table I with $\Delta\alpha$ as an argument.

In our example we have $\Delta\alpha = 2^s.3888$, entering Table I with this argument we get the retardation in 1 hour of longitude $2^s.30968$ or $2^s.310$ which is tabulated in the 3rd column opposite April 4; for the motion in R. A. $148^s.85$ and

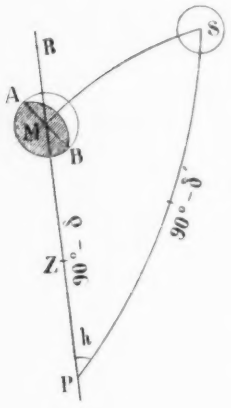
* To appear in next number.

$$\log \frac{60^2}{160.164 - \Delta\alpha} = 1.79456$$

and from page 60, $\Delta\delta = 13''.008$, therefore motion in Decl. is $810''.54$.

The variations of the time of transit, and of the motion in R. A. and Decl. in one hour of longitude are only approximate. They are carried to a degree of exactness not warranted by the original data which are given only to the nearest unit of the first decimal place. The only use they can serve is to give the observer the approximate time of transit and to enable him to set his instrument, but if an accurate comparison of the tabulated and observed place of the Moon be required for any place—such as at the Goodsell Observatory, a computation of all the circumstances of the transit would have to be made de novo.

Illuminated Limbs.



From new Moon to full Moon the first (I) limb is illumined and the second (II) from full Moon to new Moon.

The north and south limbs are determined as follows:

Let M and S be the positions of the Moon and Sun at the time of the Moon's transit, P, the north pole and Z the zenith of the observer. Then in the spherical triangle PSM we have

PS = $90 - \delta'$, the Sun's north polar distance.

PM = $90 - \delta$, the Moon's north polar distance.

SPM = h, the Sun's hour angle.
= the apparent time of transit.
= $\alpha - \alpha'$,

all of which are given in the Ephemeris. If ACB be the illuminated portion seen by the observer on the meridian PZM, AB will be the line of cusps and the plane of the great circle passing through A, B and M, is perpendicular to the plane of the great circle through M and S. Put the angle ZMB = AMR = θ, then we shall have

$$PMS = \theta + 90^\circ \text{ or } -\theta + 90^\circ$$

and
$$\cot PMS = \frac{\cos\delta \tan\delta' - \sin\delta \cos h}{\sin h}$$

or $$\pm \tan \theta = \frac{\tan \delta' - \tan \delta \cos h}{\sin h \sec \delta} \qquad (34)$$

Now since $\sin h \sec \delta$ is positive when $h < 180°$, and negative when $h > 180°$, the sign of $\tan \theta$ will be the same as that of the numerator of the second member of the equation, that is

$\tan \theta$ is $-$ when $\tan \delta' < \tan \delta \cos h$
" " $+$ " $\tan \delta' > \tan \delta \cos h$
" " 0 " $\tan \delta' = \tan \delta \cos h$

Put $\tan \delta \cos h = \tan \Delta$ then we shall evidently have the following criteria:

If $\delta' > \Delta$ or $\Delta - \delta' =$ a negative quantity the north limb is illuminated, and if $\delta' < \Delta$ or $\Delta - \delta' =$ a positive quantity the south limb is illuminated.

When $h = 0°$ or $180°$, $\theta = \pm 90°$ and the line of cusps is at right angles to the meridian, when $h = 90°$ or $270°$, $\Delta = 0$, and

$$\tan \theta = \frac{\tan \delta'}{\sec \delta}$$

hence if δ' is negative the *south* limb is illuminated and if positive the north limb.

When $\tan \delta' = \cos h \tan \delta$, $\theta = 0$ and the line of cusps coincides with meridian and $\tan \delta > \tan \delta'$ or $\delta > \delta'$ numerically.

The values of Δ are tabulated in Table II—a table of double entry—with δ and h as arguments, the former being at the top and bottom and the latter at the left and right sides of the page.

The Sun's approximate declination for every 5th day, is also added for convenience but when a very accurate computation has to be made as in the case where doubt exists as to which limb is actually illuminated, all the quantities must be accurately interpolated for the apparent time of transit.

In our example we have

Mean time of transit.....	April $4^d\ 8^h\ 15^m.95$
Equation of time (page 379).....	$-\ 2\ .9$
Apparent time of transit.....	$8^h\ 13^m$
Moon's declination (δ).....	$+\ 19°\ 51'\ 6''.9$
Sun's declination (δ') approximate..	$+\ 5\ \ 54\ \ 5\ \ .0$

Entering Table II we find

$$\Delta = -11°.4$$

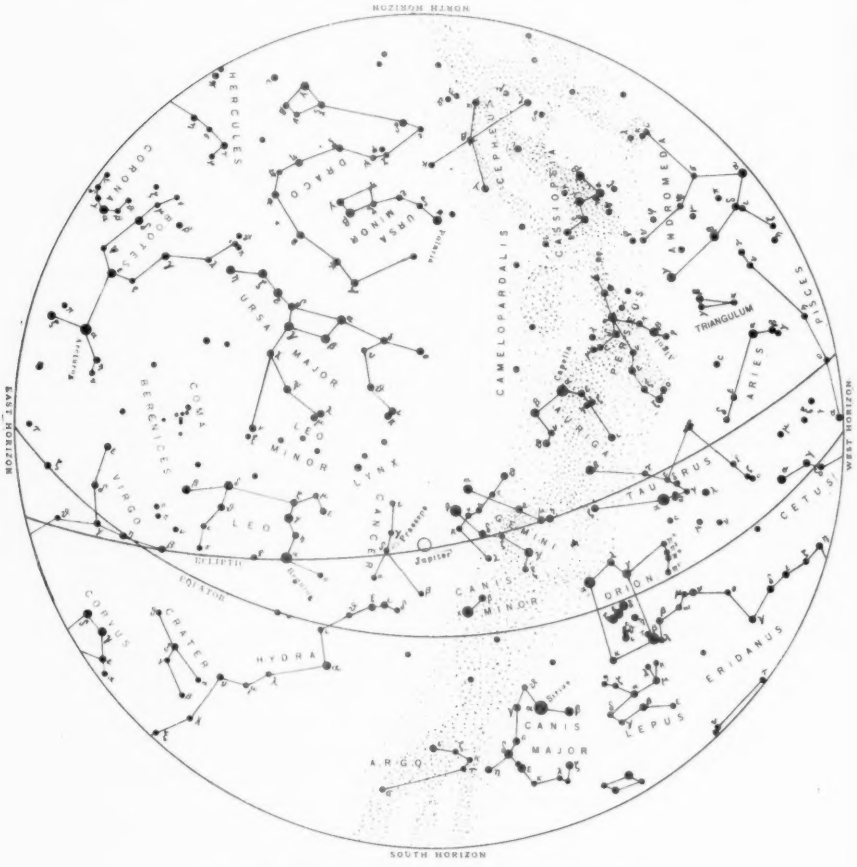
then $$\Delta - \delta' = -11°.4 - 5°.9 = -17°.3$$

a negative quantity, therefore the north limb is the bright one, and is marked *N*. When both limbs are nearly equally illuminated as on April 8, the one which is slightly deficient is printed in smaller type. At such times a very accurate examination must be made.

(TO BE CONTINUED.)

THE PLANETS AND THE CONSTELLATIONS FOR MARCH.

Mercury will reach greatest western elongation, 27° 20′ from the Sun, March 5, and will therefore be visible as a morning planet during the first half of the month. The observer should look toward the southeast horizon a little way east from Venus in order to see Mercury. The phase of Mercury is at first quarter on March 1 and is increasingly gibbous during the month.



THE CONSTELLATIONS AT 9h P. M. MARCH 1, 1896.

Venus is to be seen in the morning toward the southeast. Her phase increases from 0.83 to 0.90 while her light diminishes from 66 to 57 during the month. On the morning of the 14th Venus will be close to the fifth magnitude star μ Capri-

corni, passing between 5′ and 6′ to the south of the star. Venus will be in conjunction with the waning Moon on the morning of March 11 at $8^h\ 19^m$ Central time. Observers in South America may witness an occultation of the planet. Northern observers will see the planet about a degree to the north of the Moon.

Mars is about 12° to the west of Venus on the 1st, and the apparent distance between the two planets increases to 24° at the end of the month. Mars is now about 179,000,000 miles from the earth and the apparent diameter of his disc is only 5″, so that we cannot yet expect to see much of the surface markings.

Jupiter is in most convenient position for observation now, crossing the meridian at a high altitude at about half past nine in the evening. The position of Jupiter among the stars is indicated upon our map for this month. It is midway between the constellations Cancer and Gemini.

The notch in the southern red belt marking the location of the great red spot will be near the central meridian of Jupiter's disc at the following times:

March 1	7 P. M.	March 11	5 P. M.	March 22	2 A. M.
3	1 A. M.	12	11 "	22	9 P. M.
3	9 P. M.	13	7 "	23	5 "
4	5 "	15	1 A. M.	24	11 "
5	10 "	15	9 P. M.	25	7 "
6	6 "	16	4 "	27	1 A. M.
7	12 midn	17	10 "	27	9 P. M.
8	8 P. M.	18	6 "	28	4 "
10	2 A. M.	19	12 midn	29	10 "
10	9 P. M.	20	8 P. M.	30	6 "
				31	12 midn.

It will be interesting to our readers to try and see if they can detect any trace of the red spot still remaining. Though the month of March is generally blustery and cloudy, yet we may expect two or three good observing nights.

Saturn crosses the meridian at about half past four in the morning, 15° south of the equator. An astronomy class visiting Goodsell Observatory in the latter part of January obtained a good view of the planet and his rings. Most of those, however, who wish to see this superb object will wait until the warmer weather comes and the planet is visible in the more agreeable evening hours.

Uranus is with Saturn, about 5° southeast of the latter, in the constellation Libra. His right ascension is $15^h\ 29^m$ and his declination south 18° 37′.

Neptune is in Taurus in right ascension $4^h\ 57^m$, declination north 21° 13′. There are a couple of stars in this vicinity a little brighter than the planet, but the latter can be recognized by his dull blue color.

The *Sun* crosses the equator on the 19th of March at 8^h P. M. Central Standard time. He enters then the sign Aries ♈, but is actually in the western part of the constellation Pisces. Spring theoretically begins at this time, but practically in our northern latitud · we are not sure of the end of winter until nearly the first of May.

Comet Perrine was observed at Kiel February 13.708 in right ascension $19^h\ 44^m\ 47^s.9$, declination south 2° 22′ 38″. This is only 6ˢ west and 3′ north of the calculated place according to Mr. Perrine's ephemeris in our last number, page 327.

Jupiter's Satellites for March.

Central Standard Time.

Phases of the Eclipses of the Satellites for an Inverting Telescope.

I. r

III. d r

II. r

IV. d r

Configuration 10h 0m p. m. for an Inverting Telescope.

Day.	West.	East.
1	·2 3·	○ ·1 4·
2	3· 4· 1·	○ ·2
3	4· 3	○ 2· ·1
4	4· 2· ·1 ·3	○
5	4·	○ 1· ·3 ·2●
6	·4 ·1	○ 2· ·3
7	○1· ·4 2·	○ 3·
8	·4 ·2 3·	○ ·1
9	3· ·4 1·	○ ·2
10	·3	○ ·4 2· ·1
11	2· 1· ·3	○ ·4
12		○ 1· ·3 ·4 ·2●
13	·1	○ 2· ·3 ·4
14	2·	○ 1· 3· ·4
15	○3· ·2	○ ·4 ·1●
16	3· 1·	○ ·2 4·
17	·3	○ ·12· 4·
18	2· ·31·	○ 4·
19	4· ·2	○ 1· ·3
20	4· ·1	○ ·2 ·3
21	4·	2·○ 1· 3·
22	4· ·2	·1○3·
23	○1· ·4 3·	○ ·2
24	·4 ·3	○ ·1 2·
25	·4 ·32· 1·	○
26	·4·2	○ ·3 ·1
27	·1	○ ·4 ·2 ·3
28	○2·	○ 1· 3· ·4
29	·2 ·1	○ 3· ·4
30	○1· 3·	○ ·2 ·4
31	3·	○ ·1 2· 4·

Phenomena of Jupiter's Satellites.

Central Time.

	h	m			
Mar. 1	12	48 P. M.	III	Tr.	In.
	4	13 "	III	Sh.	In.
	4	27 "	III	Tr.	Eg.
	5	25 "	I*	Oc.	Dis.
	7	53 "	III*	Sh.	Eg.
	8	34 "	I*	Ec.	Re.
2	6	17 A. M.	II	Oc.	Dis.
	7	53 "	IV	Tr.	In.
	10	52 "	II	Ec.	Re.
	12	33 P. M.	IV	Tr.	Eg.
	2	44 "	I	Tr.	In.
	3	36 "	I	Sh.	In.
	4	0 "	IV	Sh.	In.
	5	4 "	I	Tr.	Eg.
	5	56 "	I*	Sh.	Eg.
	8	44 "	IV*	Sh.	Eg.
3	11	52 A. M.	I	Oc.	Dis.
	3	3 P. M.	I	Ec.	Re.
4	12	24 A. M.	II*	Tr	In.
	2	11 "	II*	Sh.	In.
	3	21 "	II*	Tr.	Eg.
	5	6 "	II	Sh.	Eg.
	9	11 "	I	Tr.	In.
	10	5 "	I	Sh.	In.
	11	31 "	I	Tr.	Eg.
	12	25 P. M.	I	Sh.	Eg.
5	2	25 A. M.	III*	Oc	Dis.
	6	4 "	III	Oc.	Re.
	6	10 "	III	Ec.	Dis.
	6	19 "	I	Oc.	Dis.
	9	32 "	I	Ec.	Re.
	9	42 "	III	Ec.	Re.
	7	27 P. M.	II*	Oc.	Dis.
6	12	9 A. M.	II*	Ec.	Re.
	3	38 "	I	Tr.	In.
	4	34 "	I	Sh.	In.
	5	58 "	I	Tr.	Eg.
	6	54 "	I	Sh.	Eg.
7	12	44 "	I*	Oc.	Dis.
	4	1 "	I	Ec.	Re.
	1	38 P. M.	II	Tr.	In.
	3	30 "	II	Sh.	In.
	4	31 "	II	Tr.	Eg.
	6	25 "	II*	Sh.	Eg.
	10	5 "	I*	Tr.	In.
	11	2 "	I*	Sh.	In.
8	12	25 A. M.	I*	Tr.	Eg.
	1	22 "	I*	Sh.	Eg.
	4	19 P. M.	III	Tr.	In.
	7	13 "	I*	Oc.	Dis.
	7	57 "	III*	Tr.	Eg.
	8	12 "	III*	Sh.	In.
	10	20 "	I*	Ec.	Re.
	11	52 "	III*	Sh.	Eg.
9	8	38 A. M.	II	Oc.	Dis.
	1	27 P. M.	II	Ec.	Re.
	4	32 "	I	Tr.	In.
	5	31 "	I*	Sh.	In.
	6	52 "	I*	Tr.	Eg.
	7	51 "	I*	Sh.	Eg.
10	1	41 P. M.	I	Oc.	Dis.
	4	15 "	IV	Oc.	Dis.
	4	58 "	I	Ec.	Re.
	8	54 "	IV*	Oc.	Re.
11	1	49 A. M.	IV*	Ec.	Dis.
	2	50 "	II*	Tr.	In.
	4	48 "	II	Sh.	In.
	5	45 "	II	Tr.	Eg.
	6	27 "	IV	Ec.	Re.
	7	43 "	II	Sh.	Eg.
	10	59 "	I	Tr.	In.
	12	0 M.	I	Sh.	In.
	1	19 P. M.	I	Tr.	Eg.
	2	20 "	I	Sh.	Eg.
12	5	59 A. M.	III	Oc.	Dis.
	8	8 "	I	Oc.	Dis.
	9	37 "	III	Oc.	Re.
	10	10 "	III	Ec.	Dis.
	11	27 "	I	Ec.	Re.
	2	41 P. M.	III	Ec.	Re.
	9	50 "	II*	Oc.	Dis.
13	2	45 A. M.	II	Ec.	Re.
	5	26 "	I	Tr.	In.
	6	28 "	I	Sh.	In.
	7	46 "	I	Tr.	Eg.
	8	48 "	I	Sh.	Eg.
14	2	35 "	I	Oc.	Dis.
	5	46 "	I	Ec.	Re.
	4	2 P. M.	II	Tr.	In.
	6	7 "	II*	Sh.	In
	6	57 "	II*	Tr.	Eg.
	9	2 "	II*	Sh.	Eg.
	11	53 "	I*	Tr.	In.
15	12	57 A. M.	I*	Sh.	In.
	2	13 "	I	Tr.	Eg.
	3	17 "	I	Sh.	Eg.
	7	54 P. M.	III*	Tr.	In.
	9	3 "	I*	Oc.	Dis.
	11	32 "	III*	Tr.	Eg.
16	12	12 A. M.	III*	Sh.	In.
	12	25 "	I*	Ec.	Re.
	3	52 "	III	Sh.	Eg.
	11	2 "	II	Oc.	Dis.
	4	2 P. M.	II	Ec.	Re.
	6	21 "	I*	Tr.	In.
	7	26 "	I*	Sh.	In.
	8	41 "	I*	Tr.	Eg.
	9	46 "	I*	Sh.	Eg.
17	3	30 "	I	Oc.	Dis.
	6	53 "	I*	Ec.	Re.
18	5	16 A. M.	II	Tr.	In.
	7	25 "	II	Sh.	In.
	8	11 "	II	Tr.	Eg.
	10	20 "	II	Sh.	Eg.
	12	48 P. M.	I	Tr.	In.
	1	54 "	I	Sh.	In.
	3	8 "	I	Tr.	Eg.
	4	14 "	I	Sh.	Eg.
	11	35 "	IV*	Tr.	In.
19	4	14 A. M.	IV	Tr.	Eg.

19	9	34	A. M.	III	Oc.	Dis.
	9	58	"	I	Oc.	Dis.
	10	1	"	IV	Sh.	In.
	1	15	P. M.	III	Oc.	Re.
	1	22	"	I	Ec.	Re.
	2	9	"	III	Ec.	Dis.
	2	47	"	IV	Sh.	Eg.
	5	41	"	III*	Ec.	Re.
20	12	15	A. M.	II*	Oc.	Dis.
	5	20	"	II	Ec.	Re.
	7	16	"	I	Tr.	In.
	8	23	"	I	Sh.	In.
	9	36	"	I	Tr.	Eg.
	10	43	"	I	Sh.	Eg.
21	4	25	"	I	Oc.	Dis.
	7	51	"	I	Ec.	Re.
	6	30	P. M.	II*	Tr.	In.
	8	44	"	II*	Sh.	In.
	9	25	"	II*	Tr.	Eg.
	11	40	"	II*	Sh.	Eg.
22	1	43	A. M.	I*	Tr.	In.
	2	52	"	I	Sh.	In.
	4	3	"	I	Tr.	Eg.
	5	12	"	I	Sh.	Eg.
	10	53	P. M.	I*	Oc.	Dis.
	11	34	"	III*	Tr.	In.
23	2	20	A. M.	I	Ec.	Re.
	3	12	"	III	Tr.	Eg.
	4	11	"	III	Sh.	In.
	7	52	"	III	Sh.	Eg.
	1	28	P. M.	II	Oc.	Dis.
	6	38	"	II*	Ec.	Re.
	8	11	"	I*	Tr.	In.
	9	20	"	I*	Sh.	In.
	10	31	"	I*	Tr.	Eg.
	11	40	"	I*	Sh.	Eg.
24	5	21	"	I	Oc.	Dis.
	8	49	"	I*	Ec.	Re.
25	7	44	A. M.	II	Tr.	In.
	10	2	"	II	Sh.	In.
	10	39	"	II	Tr.	Eg.
	12	58	P. M.	II	Sh.	Eg.
	2	39	"	I	Tr.	In.
25	3	49	"	I	Sh.	In.
	4	59	"	I	Tr.	Eg.
	6	9	"	I*	Sh.	Eg.
26	11	49	A. M.	I	Oc.	Dis.
	1	19	P. M.	III	Oc.	Dis.
	3	18	"	I	Ec.	Re.
	4	57	"	III	Oc.	Re.
	6	9	"	III*	Ec.	Dis.
	9	41	"	III*	Ec.	Re.
27	2	42	A. M.	II*	Oc.	Dis.
	7	55	"	II	Ec	Re.
	8	29	"	IV	Oc.	Dis.
	9	7	"	I	Tr.	In.
	10	18	"	I	Sh.	In.
	11	27	"	I	Tr.	Eg.
	12	38	P. M.	I	Sh.	Eg.
	1	8	"	IV	Oc.	Re.
	7	53	"	IV*	Ec.	Dis.
28	12	33	A. M.	IV*	Ec.	Re.
	6	27	"	I	Oc.	Dis.
	9	46	"	I	Ec.	Re.
	8	59	P. M.	II*	Tr.	In.
	11	21	"	II*	Sh.	In.
	11	54	"	II*	Tr.	Eg.
29	2	17	A. M.	II	Sh.	Eg.
	3	35	"	I	Tr.	In.
	4	46	"	I	Sh.	In.
	5	55	"	I	Tr.	Eg.
	7	6	"	I	Sh.	Eg.
30	1	45	"	I	Oc.	Dis.
	3	19	"	II	Tr.	In.
	4	15	"	I	Ec.	Re.
	6	57	"	II	Tr.	Eg.
	8	11	"	II	Sh.	In.
	11	52	"	II	Sh.	Eg.
	3	56	P. M.	II	Oc.	Dis.
	9	13	"	II*	Ec.	Re.
	10	3	"	I*	Tr.	In.
	11	15	"	I*	Sh.	In.
31	12	23	A. M.	I*	Tr.	Eg.
	1	35	"	I	Sh.	Eg.
	7	13	P. M.	I*	Oc.	Dis.
	0	44	"	I*	Ec.	Re.

Occultations Visible at Washington.

Date 1896.		Star's Name.	Magnitude.	IMMERSION Washington M. T. h	m	Angle from N pt. °	EMERSION Washington M. T. h	m	Angle from N pt. °	Duration. h	m
Mar.	4	4 Scorpii	6.3	12	47	91	13	48	317	1	1
	9	17 Capricorni	6.0	16	20	124	17	7	208	0	47
	21	136 Tauri	5.3	10	5	156	10	42	226	0	37
	22	39 Geminorum	6.3	12	46	137	13	33	257	0	47
	22	40 Geminorum	6.3	13	18	174	13	38	219	0	20
	23	κ Geminorum	3.7	5	24	149	6	23	240	0	59
	25	23 Leonis	6.3	12	44	140	13	43	207	0	59
	26	49 Leonis	6 0	5	33	87	6	28	331	0	55
	26	37 Sextantis	6.3	12	53	138	13	56	295	1	3
	26	38 Sextantis	7.8	13	26	104	14	24	327	0	58

Minima of the Variable Stars of the Algol Type.

[Given to the nearest hour in Central Standard Time.]

U CEPHEI.

1896.	d	h
Apr.	3	14
	8	13
	13	13
	18	13
	23	12
	28	12

ALGOL.

Apr.	26	11
	29	7

R CANIS MAJ.

Apr.	7	8
	8	11
	15	7
	16	10
	24	9

S CANCRI.

1896.	d	h
Apr.	12	7

δ LIBRÆ.

Apr.	4	10
	11	10
	18	9
	25	9

U CORONÆ.

Apr.	4	11
	11	9
	18	7

U OPHIUCHI.

1896.	d	h
Apr.	3	15
	4	11
	8	16
	9	12
	13	16
	14	12
	18	17
	19	13
	24	14
	29	15

D. M. + 17°,4367.

Mar.	3	0
	7	19
	12	15
	17	10

CONT.

D. M. + 17°,4367.

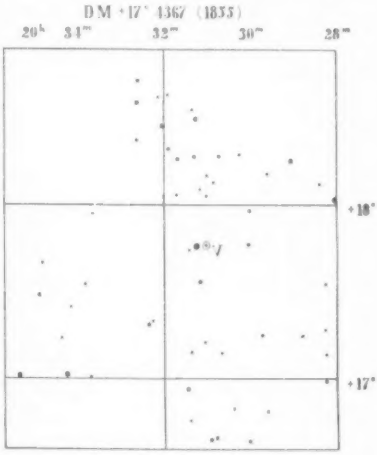
1896.	d	h
Mar.	22	5
	27	1
	31	20
Apr.	5	15
	10	11
	15	6
	20	1
	24	21
	29	16

The above data are from advance sheets of the *Vierteljahrsschrift*, sent by the kindness of the author, Dr. Ernst Hartwig, except for the new variable D. M. + 17°,4367, which were computed from Searle's elements, (See separate article in another part of this number).

J. A. PARKHURST.

Marengo, Ill., 1896, Feb. 4.

A Remarkable Algol Type Variable.—The announcement is made in Harvard College Observatory Circular No. 3 of the discovery of a new Algol type variable of unusual range of variation. It is the 9.1 magnitude Durchmusterung star + 17°,4367, position for 1900, R. A. 20h 33m.1 Decl. + 17° 56′. It did not appear on a photograph taken Sept. 26, 1891, while on seventy-one other plates it showed with the above magnitude. It was observed visually by Professor Searle and found to be diminishing in brightness Dec. 12, 1895 from 10h 42m to 11h 15m Greenwich Mean Time, when clouds interfered and prevented a complete determination of the minimum. It was again found faint by Professor Searle Dec. 17, and the prediction was made that it would be fainter than the eleventh magnitude 1896 Jan. 5, from 11h.6 to 15h.8 Greenwich Mean Time. This minimum was observed by Mr. P. S. Yendell at Dorchester, Mass., who reported in the *Astronomical Journal*, No. 364 that it was invisible (below 11 magnitude) at 10h 24m and 11h 4m Greenwich M. T., a fairly close agreement with the predicted time.



The lower limit of the star's variation does not seem to be yet ascertained, but it is distinguished from all other Algol type variables by its faintness at minimum; the nearest approach among stars previously known being S Canci, which falls to 9.8 magnitude. It is hoped that further observations will be made as soon as the star comes out of the morning twilight, and accordingly an ephemeris is given with the other Algol type stars in the usual place in this number, computed with the period $4^d\ 19^h\ 21^m.2$ as announced by Professor Pickering in Harvard Circular No. 4. The accompanying chart, giving the stars to the 10th magnitude within 1° of the variable will aid in identifying it. There is a 7th magnitude star 14^s following and 1′ south of the variable. J. A. PARKHURST.

Ephemeris of Short-Period Variables.

MARCH, 1896.

[Greenwich Mean Time].

2279 T Monocerotis.	
Max.	Min.
11.36	3 43
	30.43

2509 ζ Geminorum.	
6.83	1.81
16.98	11.96
27.13	22.12

4805 W Virginis.	
4.60	
21.87	13.67
	30.94

6758 β Lyr.æ.	
	1.83
	14.75
	27.67

6404 Y Ophiuchi.	
6.61	
23.74	17.49

6984 U Aquilæ.	
Max.	Min.
1.13	
8.16	5.91
15.19	12.94
22.21	19.96
29.24	26.99

7124 η Aquilæ.	
4.35	1.97
11.52	9.15
18.70	16.32
25.88	23.50
	30.67

7149 S Sagittæ.	
7.72	4.32
16.10	12.70
24.49	21.09
	29.47

7437 X Cygni.	
Max.	Min.
13.24	6.44
29.63	22.83

7483 T Vulpeculæ.	
5.16	3.86
9.59	8.29
14.03	12.73
18.46	17.16
22.90	21.60
27.34	26.04
31.77	30.47

8073 δ Cephei.	
5.63	4.04
10.99	9.40
16.36	14.77
21.73	20.14
27.09	25.50

P. S. Yendell.

New Variable Star of the Algol Type.—The star B. D. + 17° 4367, magn. 9.1, whose approximate position for 1900 is in R. A. $20^h\ 33^m.1$, Dec. +17° 56′, appears to be a variable star of the Algol type. On July 18, 1895, Miss Louisa D. Wells found that no trace of this star appeared on the photograph I 4359, taken with the 8-inch Draper telescope on September 26, 1891, exposure 16 m. On 71 other plates taken from June 30, 1890, to October 5, 1895, the star appears of its normal brightness. On December 12, 1895, at $10^h\ 42^m$ Greenwich Mean Time, Professor Arthur Searle, who had watched this star on several nights, found it more than a magnitude fainter than usual. During the next half hour it diminished about half a magnitude more. Meanwhile, a photograph taken with the 8-inch Draper telescope, I 14036, confirmed the diminution in light. Unfortunately, $11^h\ 15^m$ G. M. T., clouds covered the region, and the star, although carefully looked for, was not seen again that evening. The change in brightness appears to be rapid and the range of variation to be large, exceed-

ing two magnitudes. The nearest bright star is B. D. + 17° 4370, magn. 7.0, which follows 14ˢ and is south 1′. The variability of B. D. + 17° 4370 has been suspected by Espin (English Mechanic, Vol. LXII, 334) and also independently by Mrs. Fleming in 1890.

EDWARD C. PICKERING.

H. C. Obs'y Circular, No. 2, December 13, 1895.

Maxima and Minima of Long Period Variables.

MAXIMA.

1896 March.

Date	No.	Star.
6	3184	T Hydræ.
7	8068	S Lacertæ.
8	6512	T Herculis.
8	2100	U Orionis.
11	6207	Z Ophiuchi.
12	6849	R Aquilæ.
12	4521	R Virginis.
13	5174	RS Virginis.
16	5504	S Coronæ.
16	5511	RS Libræ.
17	1222	R Persei.
21	1805	V Orionis.
21	8373	S Pegasi.
22	715	S Arietis.
22	5190	R Camelop.
27	4407	R Corvi.
27	5688	R Libræ.
27	494	R Sculptoris.

1896 April.

4	8153	R Lacertæ.
4	5438	Y Libræ.

MAXIMA CONT.

1896 April.

Date	No.	Star.
5	2780	T Geminorum
7	3825	R Ursæ Maj.
10	3425	X Hydræ
11	6900	W Aquilæ.
15	7577	X Capricorni.
23	7999	X Aquarii.
23	782	R Arietis.
24	3994	S Leonis.
28	7428	V Cygni.
30	5758	X Herculis.

MINIMA.

1896 March.

1	5758	X Herculis.
1	1717	V Tauri.
11	7242	S Aquilæ.
17	(2445)	W Monocerotis.
18	1574	W Tauri.
21	7609	T Cephei.
23	107	T Cassiopeæ.

MINIMA CONT.

1896 March.

Date	No.	Star.
25	5889	U Herculis.
27	845	R Ceti
28	5583	X Libræ.
30	893	U Ceti.

1896 April.

2	1761	R Orionis.
3	2213	η Geminorum.
6	1855	R Aurigæ.
7	7085	RT Cygni.
10	114	S Ceti.
11	5157	S Bootis.
11	4596	U Virginis.
12	7192	Z Cygni.
14	5430	T Libræ.
14	6905	R Sagittarii.
19	5494	S Libræ.
24	5194	V Bootis.
25	7560	R Vulpeculæ.
29	8600	Cassiopeæ.

NOTE:—The star W Monocerotis is on the unconfirmed list in Chandler's "Revised Supplement to Second Catalogue of Variable Stars." It has been given the letter "W" by Hartwig, from whose observations the above prediction of minimum is made. Its position for 1855 is R. A. 6ʰ 45ᵐ 19ˢ, Decl. — 6° 58′.6.

PRACTICAL SUGGESTIONS

The Study of Astronomy.—There never was a time in the world's history when more interest was manifested in the study of astronomy than the present. The completion of the great Lick telescope marked an era in astronomical science which had a tendency to popularize the study. And now another advance has been made by the completion of the magnificent instrument for the Chicago University which will be a great incentive to the lovers of our most noble science. The equipment of a college or university is no longer considered complete unless an astronomical Observatory forms a part. Astronomical societies are forming in most of the enlightened countries of the Earth. Every modern language now has its mathematical and astronomical periodicals conducted by able professional hands. Many popular treatises have been written in all these languages with a view to lead the public to the study of the fascinating science of astronomy. All this is very gratifying to the lovers of the "bewitching" science.

Many of the most profound astronomers were lead to the study by the perusal of some popular and unpretentious volume in their youth. Burritt's Geography of the Heavens has started many a young astronomer on the road to fame. Webb's Celestial Objects for Common Telescopes has pointed out to the amateur observer what to do with his telescope, which he did not know before. Doubtless many anxious, inquiring minds are now waiting at the portals for directions how to proceed to gain admission to the Temple of Astronomy. The design of this article is to add a mite towards popularizing the study of astronomy by formulating an outline on a reading course in mathematics and astronomy for self-instruction of popular readers and students who wish to fit themselves for college work in astronomy.

We will divide our subject into five distinct courses:

I. Course in Popular Astronomy.
II. Course in Observational Astronomy.
III. Course in General Astronomy.
IV. Course in Practical Astronomy.
V. Course in Theoretical Astronomy.

The basis of astronomy is mathematics. One cannot advance far in astronomical investigations unless he has a thorough knowledge of several branches of pure and applied mathematics. However, a very meagre knowledge of mathematics is sufficient to pursue course I, Popular Astronomy. But before undertaking to read this course the student should prepare for it by reading a course in plane and solid geometry including spherical geometry, and should study the conic sections treated synthetically. A knowledge of the principles of optics is also essential. After this preparation a good elementary text-book on astronomy may be read with profit. Young's Lessons in Astronomy and Sharpless and Philip's Astronomy for schools and general readers are recommended as suitable for this course.

Course II in Observational astronomy is very comprehensive embracing all the work of the professional astronomer in the well equipped Observatory to that of the amateur who watches the sky through his opera glass. It is not our purpose here to touch upon the work of the professional, but to outline for the beginner possessed of some astronomical instrument for observation, no matter how humble. The preparation for this course depends entirely upon what kind of work the observer desires to do. If he possesses a good opera glass, he may do considerable work with it. It is wonderful what such an instrument reveals in the heavens! The observer should make careful drawings of whatever he sees and preserve them for reference. Garrett P. Servis' book, Astronomy through an Opera Glass, is recommended as a good guide for those using this instrument. Let not the observer be discouraged because his work seems meagre. Galileo's telescope with which he made his discoveries was but little better than an opera glass, yet he added to astronomical knowledge four of Jupiter's satellites, the sunspots, and other useful phenomena. If the observer possesses a good equatorial telescope of four to six inches aperture or a larger and a good astronomical clock, he can do much good work in observational astronomy. He has a choice of many branches of observational work. It is recommended that he select one line of work and apply all his energy to it. There is useful work in observing the sunspots with careful drawings and records of them. He may spend all his time in studying planetary markings. Possessing a good position micrometer, he can engage in measuring double stars. If his instrument is equipped with spectroscopic attachment, he can go into spectrum analyses. With the necessary appliances celestial photography may be engaged in. A good guide

for whatever branch of work he may choose is Webb's Celestial Objects for Common Telescopes. The directions given in this book carefully followed will make the observer skillful and useful to astronomical science.

The preparation needed to read a work on General Astronomy, say Young's text, which is the best extant, comprises a thorough knowledge of algebraic formulæ, proficiency in solid geometry including spherical geometry, a practical knowledge of plane and spherical trigonometry, and the principles of optics.

For the study of Practical astronomy and also Theoretical astronomy the most thorough knowledge of mathematics is needed. The preparation for these courses should embrace plane and spherical trigonometry, conic sections, differential and integral calculus, the theory of equations, mechanics, and the method of least squares. No one should attempt to read courses IV and V without a thorough knowledge of all these branches of mathematics. These subjects are not beyond the reach of ordinary minds. By diligent application they may be mastered in a few months and for the time so spent one is amply rewarded; for it is by the higher mathematics that the human mind is carried out into the farthest confines of esoteric nature and lead to realize the wisdom and majesty of the great Ruler of the universe. J. M. T.

GENERAL NOTES.

It is possible that this publication is sent to some subscribers who have not renewed their orders for the same. If this is so such names have been overlooked. It is not intentional. It will be a favor for any such to notify the publisher.

Dr. Morrison's Articles explanatory of the American Ephemeris are continued in this number. The value of these articles to the student of astronomy is very great and is manifestly appreciated. They are not easy reading for all our patrons, but they are exceedingly helpful to a considerable number who have read mathematics enough to understand the methods employed in demonstration or illustration. Dr. Morrison has felt that he has not reached the degree of easy reading in the manner of discussion chosen which was best suited to the aim and object of our publication. In this we want to assure him that we do not see how he could have done better without adopting a method extremely long and hence undesirable. The popular reader is not interested in such themes, yet the student of astronomy is, and he should have the needed help. This is only popularizing the American Ephemeris for a very considerable portion of our patronage. We have to admit that we are not popularizing this matter to make it read like a love story. This we would not do if we could.

Lick Observatory Total Eclipse Expedition to Japan, Aug. 1896.—Colonel C. F. Crocker of the Board of Regents of the University of California, generously provides the funds necessary for an expedition from Lick Observatory to view the total solar eclipse of the Sun August, 1896. It should also be remembered that Colonel Crocker at his own expense sent out the Lick Observatory eclipse expedition in December 1889 to Cayenne.

The programme for this year's expedition is to be wholly photographic. Professor Schaeberle will make large scale photographs of the corona with a lens whose focal length is 40 feet, like those made in Chile in 1893, besides smaller ones

by the aid of the Floyd photographic telescope. Mr. Burckhalter, of Chabot Observatory, Oakland, will use a photographic telescope of 4-inches aperture and 20 feet focal length, provided at the expense of Hon. W. M. Pierson. Dr. G. E. Shuey and Louis C. Masten accompany the expedition, at their own cost, as assistants. Professor H. Terao, Director of the Imperial Observatory of Tokyo, has kindly offered to select a member of the staff of his Observatory to accompany the Lick Observatory expedition as one of its members to its station in Japan.

Mira, o Ceti.—At Northfield we saw Mira with naked eye first on Jan. 7, after a considerable interval of cloudy weather. The brightness of the variable was then almost exactly equal to that of δ Ceti or 4.1 magnitude. It slowly increased until Feb. 1 when it was a little brighter than γ Ceti or about 3.5 magnitude. Since then it has been almost stationary and has perhaps begun to decline. Our observations have not been frequent enough to detect fluctuations.

Photographs of the spectrum of Mira were obtained here on the nights of Jan. 13, Jan. 25, Feb. 1 and Feb. 7. On these photographs the spectrum begins in the vicinity of the *b* (Magnesium) group of lines and extends nearly to H. The four principal flutings begin abruptly, being bright and sharp-edged on the side toward the red end of the spectrum and fading out irregularly toward the violet end. They may all be subdivided into smaller flutings of the same general character. Near G the flutings cease and from G to H the spectrum is faint and almost continuous, showing traces of dark lines. The two hydrogen lines G and *h*, however, are bright and appear to have increased in brightness and sharpness during the period in which the photographs were taken. The F line, which is also a hydrogen line, can scarcely be distinguished from the other bright lines of the fluting in which it is situated. H. C. W.

103 T Andromedæ.—Any person who has observed maxima of this star will confer a favor upon the undersigned by sending the dates and particulars to
P. S. YENDELL, 19 Winter St., Dorchester, Mass.

A New Star in Centaurus.—A new star in the constellation Centaurus was found by Mrs. Fleming on December 12, 1895, from an examination of the Draper Memorial photographs. Its approximate position for 1900 is in R.A. 13^h $34^m.3$, Decl. $-31°$ 8′. Attention was called to it from the peculiarity of the spectrum on Plate B 14151, taken at Arequipa on July 18, 1895, with the Bache telescope, exposure 52^m. The spectrum resembles that of the nebula surrounding 30 Doradus, and also that of the star A. G. C. 20937, and is unlike that of an ordinary nebula or of the new stars in Auriga, Norma, and Carina. This object is very near the nebula N. G. C. 5253, which follows $1^s.28$, and is north 23″. No trace of it can be found on 55 plates taken from May 21, 1889, to June 14, 1895 inclusive. On July 8, 1895, it appeared on a chart plate, B 13965, and its magnitude was 7.2. On Plate B 10472 taken July 10, 1895, its magnitude was also 7.2. On December 16, 1895, a faint photographic image of it, magnitude 10.9, was obtained with the 11-inch Draper telescope, although it was very low, faint, and near the Sun. On this date, and on December 19, it was also seen by Mr. O. C. Wendell with the 15-inch equatorial as a star of about the eleventh magnitude. An examination with a prism showed that the spectrum was monochromatic, and closely resembled that of the adjacent nebula. Although the spectrum is unlike those of the new stars in Auriga, Norma and Carina, yet this object is like them in other respects. All were very faint or invisible for several years preceding

their first known appearance. They suddenly attained their full brightness and soon began to fade. Like the new stars in Cygnus, Auriga and Norma, this star appears to have changed into a gaseous nebula.

The star which was photographed in 1887 in the constellation Perseus apparently belongs to the same class. Its approximate position for 1900 was in R. A. $1^h\ 55^m.1$, Decl. $+56°\ 15'$. Eight images of it were obtained on the Draper memorial photographs in 1887, all in exactly the same place. Its photographic spectrum showed the hydrogen lines $H\beta$, $H\gamma$, $H\epsilon$, and a line near 4060, bright, and from this property it was discovered by Mrs. Fleming and assumed to be an ordinary variable star of long period. The spectrum is so faint that it is impossible to decide from it whether it should be regarded as a new star of the class of Nova Aurigæ, or as a variable star of long period like o Ceti, as the hydrogen lines are bright in both these classes of objects. The star soon faded away and does not appear on 81 photographs taken during the last eight years. It has also been repeatedly looked for in the sky without success. No trace of this star appears on two photographs taken November 3, 1885 and December 21, 1886.

A list of new stars hitherto discovered is given in the annexed table. Some changes would occur in it, if changes were made in the definition assumed for this class of objects. Early observations of several objects frequently called new stars, but which may have been comets, and whose positions are uncertain, have not been included. The stars T Bootis and U Scorpii have not been included, although they also may be new stars, as only one appearance of each has been noted. The name of the constellation is followed by the right ascension and declination for 1900, and the greatest brightness. The year of appearance is followed by the name of the discoverer; or, in the case of the earlier stars, of the principal observer:

NEW STARS.

Constellation.	R. A. 1900.		Decl. 1900.		Magn.	Year.	Discoverer.
	h	m	°	′			
Cassiopeia	0	19.2	+ 63	36	− 5?	1572	Tycho Brahe
Cygnus	20	14.1	+ 37	43	3	1600	Janson
Ophiuchus	17	24.6	− 21	24	− 4?	1604	Kepler
Vulpecula	19	43.5	+ 27	4	3	1670	Anthelm
Ophiuchus	16	53.9	− 12	44	5	1848	Hind
Scorpio	16	11.1	− 22	44	7	1860	Auwers
Corona Borealis	15	55.3	+ 26	12	2	1866	Birmingham
Cygnus	21	37.8	+ 42	23	3	1876	Schmidt
Andromeda	0	37.2	+ 40	43	7	1885	Hartwig
Perseus	1	55.1	+ 56	15	9	1887	Fleming
Auriga	5	25.6	+ 30	22	4	1891	Anderson
Norma	15	22.2	− 50	14	7	1893	Fleming
Carina	11	3.9	− 61	24	8	1895	Fleming
Centaurus	13	34.3	− 31	8	7	1895	Fleming

THE NEW ALGOL VARIABLE IN DELPHINUS.

The variable star of the Algol type, B. D. $+17°$ 4367, in the constellation Delphinus, announced in Circular No. 3, was again found to be faint by Professor Searle on December 17, 1895. From a discussion of the photographic and visual measurements so far made, it appears that its period is about $4^d\ 19^h\ 21^m.2$, and that it will again become fainter than the eleventh magnitude from $11^h.6$ to $15^h.8$, Greenwich Mean time, on January 5, 1896. EDWARD C. PICKERING.

Harvard College Observatory Circular No. 4.

Note on Easter.—The limits of Easter are March 22 and April 25, a period of 35 days. One would naturally suppose that in a very long period, the festival would occur about equally on all the days. But it is not so. From the year 1583, the one following the reformation of the calendar by Gregory, for a period of 1750 years, the irregularities are very great. The average number is 50 in the above period. The first three days and the last three fall far behind the average. It occurs on April 23, sixteen times only, and on the 24 and 25 each, twenty five times. On March 22, it occurs eleven times: March 23, fourteen times: March 24, ten times—being the least number. It occurs most frequently as follows: April 10, seventy three times: April 19, seventy two times; April 5, seventy one times; April 16, seventy times; April 11, sixty nine times; April 15, sixty eight times and on March 30 and 31, each sixty seven times. Since the earliest date above referred to, Easter has come on March 22, five times—in a period of 292 years: in the following 1458 years it will occur but six times. It last took place in 1874; the next time will be in the year 2285. In the distant future there will be another long period in which Easter will not occur on the 22d of March for 466 years: viz. from 2506 to 2971 inclusive. R. W. M.

Bright Meteor.—I had the privilege yesterday morning to see another unusually bright meteor, the trail of which behaved in a similar manner to that seen by myself Dec. 13 and described in the January number of POPULAR ASTRONOMY. Thinking it might be of interest to your readers I give description below.

1896, February 12, $4^h\ 45^m$ A. M. An unusually bright meteor made its appearance a little to the southwest of δ Cygni and passing close to β Cephei, disappeared to the northeast of this latter star. It was somewhat like Venus in color, but as much brighter than that planet as Venus is brighter than any first magnitude star; it was dazzlingly bright. Its visible path must have been nearly 50° in length, and left a trail the whole length, but both ends of which quickly disappeared leaving a central part about 5° or 6° in length and nearly as bright as Venus. Then as if the forward end of this segment were held fast, and the inertia of the meteor's flight caused the remainder to move past and below this point, producing a curious hook, the whole then commenced floating to the northeast until it vanished about 10 minutes after the advent of the meteor. In the telescope this band was about 20′ in width, and like a cloud of phosphorescence with numerous partial breaks or vacancies resembling the coal sacks of the Milky Way. W. E. SPERRA.

Randolph, Ohio, Feb 13, 1896.

The Constant of Gravitation.—Professor Rogers' remarks in the February number (pages 316-321) do not seem to me conclusive as against my statement in the November issue (page 153) that it is an error to say that the value of the Newtonian Constant, G, "*depends* upon the measured value of the mean radius of the Earth, and upon the mass of the Earth." (Vol. II, page 282).

It is of course true that from these data we can deduce the value of G, provided the Earth's mass is given in terrestrial units, such as pounds or kilograms, and not merely as a fraction of the mass of the Sun. But it is not in the least true that we *need* these data in order to compute G. Every one of the four or five purely experimental methods which have been used in determining the density of the Earth furnishes *directly* in dynes the value of the Newtonian Constant without requiring any consideration of the Earth's dimensions and mass or density. Professor Rogers shows that the change of a hundred miles in the assumed radius

of the Earth would affect his computed value of G only very slightly; but he does not consider at all what would be the effect of a change in his assumed value of the density of the Earth, which he takes as 5.6. It is this element of his calculation which is uncertain; and uncertain as one can easily see, by something more than the whole percentage of uncertainty that affects the value of G which could be directly calculated from the original experimental work which was used in determining the density.

Several other points in Professor Rogers' communications invite comment, but I will note one only,—the suggested experiment described at the foot of page 318. This must be, I think, an oversight due to inadvertence: at any rate, a half ounce ball falling 16 feet under the circumstances indicated would raise the one pound ball about six inches, i.e. until the *work* done in raising it should equal the energy of the falling mass. This, however, neglects the loss of energy due to the heat developed by the impact of the falling mass, and depending upon the nature of the materials. C. A. YOUNG.

Mr. E. Miller's Theory on the Surface Markings of the Moon Criticised.—With all due respect for Mr. Miller I think there is at least one serious objection to be raised against his theory as given in POPULAR ASTRONOMY for February.

The objection is that the theory rests on the assumption that the Moon never had an atmosphere, which assumption cannot be true if we are to accept the nebular hypothesis.

Surely it cannot be correct reasoning to suppose that because the Moon has no atmosphere now that it never had any—in fact it is very probable that the Moon went through the same or similar changes which the Earth has and will go through, only in more rapid succession owing to the smaller size of the Moon. And who knows but that the Earth will, sometime in the remote future, present an appearance much like that of the Moon to-day. But be that as it may, the fact remains that the moon-spot according to Mr. Miller, must have been formed while the Moon was still quite hot, *i. e.*, in a viscid state, and he says spots formed under such circumstances must become permanently fixed. True, they would if there was no atmospheric or aqueous agencies to erode the surface and sharp crags. But here is the point. The Moon on further cooling would allow water to become condensed on its surface, and the wind and water would wash and wear away the sharp edges, causing the Moon to present much the same appearance that the Earth does

We cannot suppose that the Moon has no air or water in its make-up, but according to the theory of cosmic development it very probably has a greater percentage of those constituents than the Earth has, though they are all absorbed by the rocks now.

Then, in the light of what has been said, how could the resulting form in the moon-spot theory of the Moon's surface constitute a photograph of its condition true to life, as long as the solar system should endure?

In conclusion, I cannot see that Mr. Miller's moon-spot theory is in sufficient harmony with well established astronomical and dynamical principles, (in its present form at least) to be considered a very tenable theory. S. L. B.

Report of Smithsonian Institution for Year Ending June, 1894.—Secretary Langley's report gives a full statement of the condition and the work in hand at the Smithsonian Institution, Washington, D. C. The detailed statement of the various features of this great Institution is instructive reading in

view of the magnitude and the character of its work. In both particulars the Smithsonian Institution is worthy of the international reputation which it has gained under the wise guardianship of the great and scholarly men that have guided its internal affairs.

We are especially interested most naturally in the report of one of its newest lines of work, organized by its present Secretary, Professor Langley; and that is the report of the Astrophysical Observatory. The work for this last year has been a continuation of the investigation of the infra-red solar spectrum described in the general body of the report for 1893. The work reported now is divided into three parts:

A. General spectroscopic work by the aid of the bolometer.

B. Special spectroscopic work by the same instrument.

C. Instrumental work, including the manufacture of new apparatus, and the perfection of the old.

The work under the first head, in its present stage, is confined to the exploration of the hitherto unexplored region in the infra-red spectrum to determine the distribution of its energy. The "appearance" of this region, as Professor Langley calls it, is already as definite in quality of spectrum as if it had been seen and measured in ordinary ways, although it must be borne in mind that no human being has senses capable of directly discriminating between the interruptions noted or of directly perceiving the form of this display of energy. "The portion of the infra spectrum shown [in one plate given in the report] which is at present farthest advanced, has been gone over several times, and each of the more than 200 lines which occupy this plate has been verified by many observations. The plate shows but a small part of the region which is now being mapped, in all of which it is believed the results will be equally encouraging. Although no investigation has been made of the meaning of the many significant lines in this great and now first exhibited region, it is reasonable to think that their study may lead to conclusions of only less importance than those resulting from the similar Frauenhofer lines in the visible spectrum."

Other parts of this interesting work are supplemental to the investigation of this new region of low wave length.

Miss O'Halloran's Observations of *o* Ceti.—I commenced to observe Mira early in last October when it seemed of the same brightness as its faint companion which is often classed as of 10th magnitude. As authorities differ slightly in their estimates of star magnitudes, in the following record, I only give the names of the stars with which it has been successively compared; and though I observed it on every clear night up to date, I select those records when the increase of brightness was decided.

October 27th, Nov. 8th, and Nov. 16th it was respectively about three tenths, seven tenths, and one magnitude brighter than its companion. Towards the end of November it seemed to decline rather than increase, but early in December commenced gradually to increase, and Dec. 10th was only one magnitude fainter than 66 Ceti, which is generally classed as of 7th magnitude. Before Dec. 20th it had gradually increased in brightness, but on that date was still fainter than 66, 70, 71 and 67 Ceti, and was not discernible in an opera glass of medium power. On Dec. 21st it was visible in the same opera glass though still fainter than the surrounding stars above mentioned.

Dec 26th. It was brighter than 71 Ceti.

Dec. 28th. It was as bright as 66 Ceti.

Dec. 31st. It seemed brighter than 66 Ceti

Jan. 1st. It was visible without magnifying power for the first time, though there was a slight fog. It may now be classed as of 6th magnitude.

Jan. 3d. It was brighter than 70 or 75 Ceti.

Jan. 5th. It was brighter than the adjacent stars of 6th magnitude and was probably of 5th magnitude, as it was as bright as *r* Ceti.

Jan. 6th. It was brighter than *r* Ceti but about seven tenths fainter than Delta Ceti. Rain and clouds hindered further observation until Jan. 18th when it was seen to be somewhat brighter than Delta.

Jan. 21st. It was not as bright as Gamma Ceti, but seems of the same magnitude as Alpha Piscium which however is a variable star, and unsuitable for comparison.

ROSE O'HALLORAN.

San Francisco, Jan. 22d, 1896.